Innovative automatic sorting system of the construction and demolition waste materials

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Abstract

Construction and Demolition Waste (CDW) generates nowadays important logistic, provision and environmental issues. Every year 3000 million of Tons are generated in Europe, out of which 25% - 30% is Construction and Demolition Waste (CDW). Construction, renovation, and demolition *projects produce large amounts of CDW that is costly to dispose. Waste processing plants extract useful materials from unsorted waste to reduce recycling costs. However today the problem of automated sorting of CDW is only partially solved, with a large part of the existing activities performed manually and this can be very tricky for dangerous material like asbestos. So far, no sorting system has been developed able to detect the aggregate (containing also pieces of bricks, tiles and glass), which is then often not recovered, or used for applications with very low added value, such as fill material in road construction. The remaining waste is usually converted into refuse derived fuel and burned for energy. This article presents a novel system architecture for sorting Construction and Demolition Waste (CDW) into high-purity, and small-size separated fractions for high-grade applications in the building industry. The method will be a "cutting-edge" technology for a modular robotic system to be easily integrated into customized end-user products. The architecture will be based upon technology for on-fly waste classification and will deliver a necessary technology demonstrator. The first result of the project is to obtain a highly automated and flexible process line for indexing and sorting CDW. Secondly, the system wants to achieve the application of vision sensors and the development of classification algorithms for fast identification and selection of CDW materials. The development of a novel grasping system for rapid CDW material handling and processing also represents a goal for the presented system. The proposed method can overcome environmental issues due to CDW, increasing the overall recycled material and maximize the technical and economic value of recycled materials and products.*

Keywords: *robotic arm, classification algorithms, recycling system.*

1. Introduction

Construction and Demolition Waste (CDW) is defined as the solid components of waste streams arising from the construction, demolition, or refurbishment of buildings or infrastructures, but does not contain Municipal Solid Waste, General Commercial, and Industrial Waste, Listed Waste, Hazardous Waste or Radioactive Waste [1]. This definition is slightly different from country to country. The ability to recycle and reuse CDW is essential to reduce environmental impacts in meeting global, national, and regional environment protection targets.

CDW represents various recyclable materials, such as metals, plastics, wood, gypsum, mineral wool, cardboard and paper, and concrete. CDW is generally considered to be harmless for the environment, and thus landfill has been commonly used. Nowadays, regarding the identification of environmental hazards and detection of the value of recycling, research is focusing on the recycling and reuse of materials. Studies have shown that approximately 90% of CDW can be recycled, which reduces the need for landfill sites [2]. The Waste Framework Directive demands the Member States take any needed measures to reach by 2020 a minimum barrier of 70 % by weight of non-hazardous CDW for reuse, recycling, and another recovery of the material backfilling operations (refilling of an excavated area [3].

CDW will be more complex than the existing one, and there is a need for shifting from traditional recycling approaches to novel recycling solutions. A basic step to achieve this objective is a relevant improvement in (automatic) sorting technology using innovative technologies that will increase the percentage of recycled materials and reused structures from CDW. The technical and economic value regarding CDW-derived materials and structures, and the building energy efficiency while minimizing future CDW expected from the next generation of buildings [4].

The rest of the paper is organized as follows: Section 2 of the paper describes the current technology used in recycling for the CDW materials; Section 3 offers information about the innovative automatic sorting system, whilst Section 4 concludes it.

2. Recycling of CDW materials in building application

The main objective of today's society is the conservation of the environment and natural recourses. Current regulations foster the use of recycled aggregates reducing the generation of waste without control and massive use of natural raw materials. Recent estimations indicate that the EU28 has 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, and bricks are estimated to make up to 90% (by weight) of all materials used [5].

The ongoing technology for recovering aggregate from CDW is based on washing, crushing, and screening processes, typically coupled with a thickener unit and filter press for water recycling. While floating materials and fine fractions are discarded, clean and sorted aggregate sizes 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 [6].

One of the goals of the RECICLARM project is to develop a novel system capable of automated indexing and sorting of CDW materials. The proposed system will overtake the limitations of current sorting technologies, developing a highly automated processing line, guaranteeing high throughput and extreme flexibility. Can handle small fragments of CDW (<5 cm), maximizing the percentage of recycled CDW from <50% up to >90%, also optimizing the quality of each fraction/material for high-value applications. Thus, the main RECICLARM results consist of:

1. Highly automated and flexible process line for indexing and sorting CDW;
2. Application of vision sensors and development of classification algorithms for fast identification and selection of CDW materials;
3. Development of a novel grasping system for rapid CDW material handling and processing.

3. Innovative automatic sorting system

One of the RECICLARM project's objectives is developing a fully automatic robot-based system to sort CDW by material classes to allow the recycling of CDW in high technical and economic value applications in the building industry from a circular economy perspective. The system will separate stones and aggregates bricks, ceramics, glass, plastic, and wood. Then will further recycle sorted material according to the particle size requirements for target applications. The sorting system comprises three elements: a sensing technology, a real-time classification algorithm, and a robotic arm with an end-effector.

Sensing technology: the sensor system aims to detect each CDW particle's surface features moving on a conveyor belt. The system's concept design previews wide spectrum hyperspectral cameras rare based on the X-Ray sensors, NearInfra Red(NIR), and visible sensors. The sensing technology's core innovation is based on the 3D/RGB multispectral cameras and IR sensors, the real-time classification, control strategy coordinating the sensing technology, and the automated cell. The advanced grasping technology manipulates small fragments of CDW. To identify different materials and maximize the quality of sorted materials is used real-time trainable classification algorithm running on a CPU. For that will use a set of sensors:

- A 3D camera or a system composed of RGB cameras will detect the color, shape, position, orientation, and the center point of each object
- Infra-Red (IR) spectral sensors will analyze the molecular structure of the object surface; this will give important information about the material composing the object
- Laser-Induced Breakdown Spectroscopy (LIBS) and Terahertz technology will be studied as possible inspection techniques to be implemented, in conjunction or alternative to IR. It will be investigated to include contact sensing technologies (in particular transducers for impedance spectrum, sound transmission spectrum) to refine or correct the classification results.

All the information collected by the sensors will feed a computer-based classifier for the sorting of the objects.

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

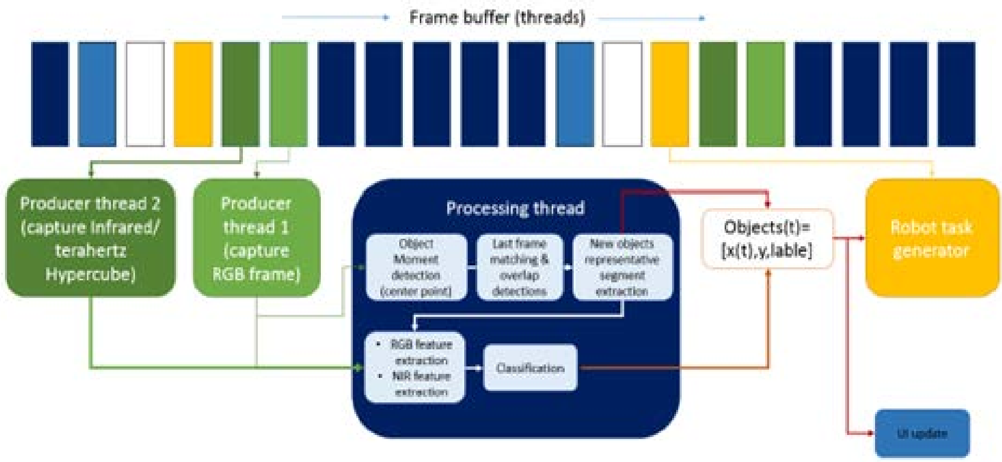

Fig. 1.Sensing software architecture for data fusion and control

Innovative Mechatronic architecture: It is expected that the RECICLARM system will be fed with input waste material in the form of particles, after crushing, on a conveyor belt. According to the classification algorithm's material class, the 6 Degrees of Freedom robotic arm will be used to handle each object and move it to the final position.

Will be developed an advanced grasping to equip the robot for pick and place. The gripper is a crucial part of the project because it strongly affects the type of fractions that can be processed. On one hand, systems such as"Universal jamming gripper" or "FESTO Flexshape gripper" allow the control system to reduce the massive amount of data computed. One robot configuration always complies with the gripper's needs. On the other hand, these flexible grippers may cube damaged by sharp objects, or the particles may not have the required shape to be suitably gripped. The system will handle small objects (<5 cm), which current smart systems cannot, which represent a large fraction of the total CDW. The robotic system will then handle each particle/object, physically separating objects made by different materials. The system's structure follows the control system's trajectories based on the objects' information (position, center point, orientation, shape, material).

Control system: The real-time classification system exploiting 3D/RGB cameras and hyperspectral sensors will provide input to the control system. The robot trajectories will be optimized to directly take the object from the conveyor belt and reach the right container (in the grasping case) in a short cycle time. The final aim is to maximize the system productivity (i.e., the amount of sorted material per time unit) by keeping the error rate as low as possible. Based on the identified objects and their materials, the system will optimize a picking sequence, maximizing the recovered objects' monetary value, thanks to dedicated algorithms.

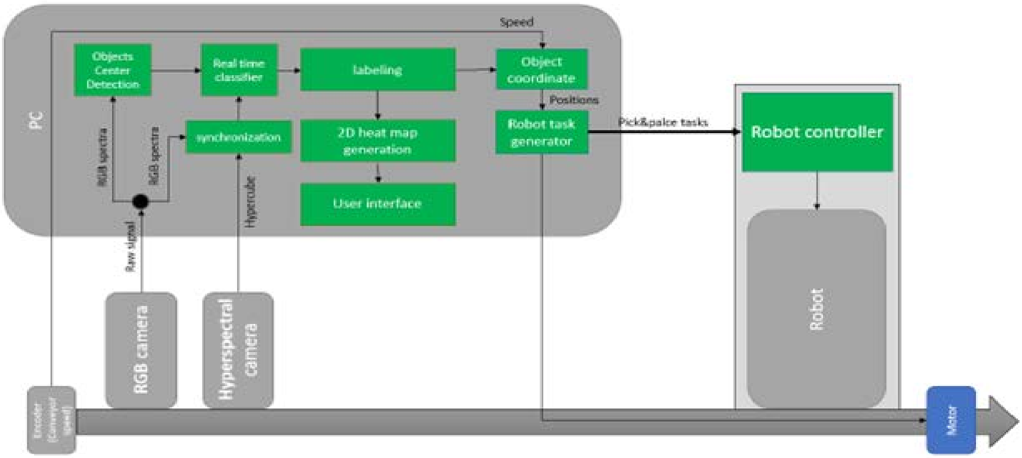

Fig. 2.RECICLARM control system layout

4. Conclusions

The main goal of the RECICLARM project is to develop a fully automatic,robot-based sorting system that will achieve a complete separation of the coarse fractions of CDW materials and obtain sorted classes of aggregates bricks, ceramics, glass, plastics, and wood. Hyperspectral analysis of each particle of crushed CDW will allow us to recognize the nature of different materials. Then will be develop a classifier to drive the robot in physical sorting. The technology will enable new kinds of possibilities for the waste industry. First, with increased automation, companies will easily increase waste sorting efficiency, resulting in a lower cost per produced ton of end fractions. Secondly, with new and improved recognition capabilities, recycling companies will have the opportunity to sort new kinds of waste types of high quality. In the future, using new knowledge can be transferred to other industry sectors, such as the recognition of different materials. As a result, this method can be generalized for the sorting of solid urban waste. Some high-value applications could be experimented with, like automatic separation of valuable materials from disposing of electronic devices. Finally, with advanced grasping technology, waste companies will be able to sort out more materials with fewer machines.

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