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Intelligent Automation for Sustainable End-of-Life Management

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Abstract

Technological advancement, economic development and increased population have resulted in increasing number of wastes generated in the worldwide. Managing the obsolete products in a sustainable manner is a challenging but meaningful act for environment, economics and human beings. Intelligent and automated technologies have been designed and developed as solutions for sustainable end-of-life management. This work aims to review the research and practices that focus on automating recycling processes, and the use of intelligent and robotic techniques in the field.

Keywords: Automation and intelligence; End-of-life management; Robotic disassembly; Recycling; Sustainability

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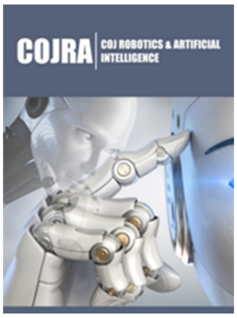

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Introduction

Automation and robotics have been widely applied in manufacturing processes, to increase production efficiency, improve the cost-effectiveness and overcome challenges in extreme working environments. However, to achieve product lifecycle sustainability, the end-of-life stage should also be taken into consideration. Due to the large variety of product types, uncertainties and complexities in product conditions, currently, the majority of the recycling activities (e.g. soring, disassembly) are undertaken manually [1]. Reducing the level of human interaction and increasing the level of machine intelligence play a significant role for achieving sustainability of waste management, in ecological, economic and social aspects. Apart from robotics used in remanufacturing and recycling, technological advances have demonstrated paced progression that supports the development of recycling sector [2]. Therefore, there is a need to understand and investigate the benefits of industrial automation and intelligence applied in waste management.

Intelligent Technologies in Recycling

Emerging technologies has greatly enabled the development of recycling, such as Internet of Things (IoT), cyber physical systems (CPS), Augmented Reality (AR), Virtual Reality (VR), cloud computing, collaboration robot (Cobot), Industry 4.0 and machine learning, etc. For example, the IoT concept was integrated with image processing and local cell technologies in an automated system to measure the real-time waste generation in food industry [3] or used for collecting and soring obsolete products effectively [4]. The information carrier, i.e. RFID or QR codes were capable of storing product information for tracking, production scheduling, remanufacturing and recycling [5]. The integration of IoT, Geographic Information Systems (GIS), and graph theory-based optimisation techniques were used to track and initiate the trash cleaning process [2]. The AR technology can be used to convey disassembly sequence information to the operator [6], or working with a Leap Motion Controller device, see-through glasses to evaluate and generate optimal disassembly strategy [7]. Furthermore, machine learning and artificial intelligence methods were used in sorting the waste materials in a highly feasible and time efficient way, including genetic algorithms and convolutional neural network classifier [2,8,9]. Based on data mining technique and observation record a repository was develop to characterise the disassembly time of joining elements, which was valuable for the evaluation of disassemblability [10]. It is noted that the knowledge derived from information technology and intelligent algorithms helped enhance the adaptability and robustness of the recycling system.

Automation in Disassembly

The concept of disassembly automation was first introduced with the set-up of a semi-automated disassembly cells for waste electronic products recycling [11]. It was designed to mitigate human interference, increase operation quality and efficiency and reduce cost. During the following decades, as research on robotic disassembly continues, an increasing number of studies developed automated systems for various products. For instance, printed circuit boards from the waste electronic components were extracted automatically through image processing, robotic handling and laser processing modules [12]. The concepts for semi-automated dismantling for LCD TVs was presented for higher productivity and flexibility [13]. After that, an evaluation and decision-making tool using matrix analysis algorism was used to identify the optimal disassembly sequence for LCD TVs [14]. With regards to the end-of-life electric vehicles (EV) management, a robotic disassembly cell was designed to extract valuable electronic components for value recovery [15]. For EV batteries, a disassembly workstation was developed where a robot and an operator can work collaboratively [16]. While the robot was assigned to perform simple and repetitive tasks, the operator was responsible for complex tasks. In order to further increase the feasibility of disassembly automation, research has focused on robotics, disassembly tooling and intelligent system design. Based on robotic disassembly cells, sensors were installed to monitor the process, cloud-based recycling process was developed for EV batteries recycling [17]. A multi-head tool was also developed for robotic disassembly of LCD screens, which was capable of sawing, grinding and removing screws [18]. Furthermore, advances in industrial automation technique enabled that multiple robots could work simultaneously in a disassembly line [19].

Conclusion

To cope with the challenging of large amount of waste, intelligent and automated techniques have been used in end-of-life management systems, closing the gap between the need for smarter recycling and technological capabilities required to achieve it. However, it is noted that the degree of automation in recycling and disassembly is not as high as it is applied in manufacturing processes (i.e. assembly, packaging and logistics, etc.), only a number of pilot or laboratory-scale projects are presented [20]. Based on the findings, current recycling activities still face the challenging caused by unpredictable conditions and significant variation in designs and materials used. Future recycling would require innovative techniques to disclose or reveal information of product design, share knowledge between manufacturers and waste management companies [21]. In addition, there is high potential to investigate and enhance the capability of human-robot collaboration [22], communication between robots and recycling tools, achieve higher productivity and efficiency by means of advanced algorithms [23], and evaluate the sustainability of recycling approaches comprehensively from three dimensions - economic, social and environmental [24].

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