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Software Applications Adopting Computer Vision for Repair, Reuse and Recycling

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Abstract: The increasing complexity and variation combined with the fast growing amount of Waste Electrical and Electronic Equipment (WEEE) entails both challenges and opportunities for reuse, repair and recycling centers in a circular economy. Recently developed computer vision systems have the potential to offer solutions to these challenges by automatically recognizing the specific product model, which entails the opportunity to facilitate the retrieval of product information and reuse, repair and recycling instructions. As a first step in the development of an application with such functionalities, the encountered challenges and opportunities, as well as the desired functionalities for such an application are investigated by means of a literature study, plant visits and discussions with several actors of this sector. Based on this analysis, an architecture has been developed for the envisaged application of which several components have already been successfully tested.

Introduction

The Circular Economy paradigm poses major challenges, as well as opportunities, as highlighted in the ambitious Circular Economy Package adopted by the European Commission (European Environment Agency, 2015a). The strategies proposed in this package envisage an additional 600 million tons of waste to be annually reused, repaired, remanufactured and recycled, yielding net annual savings for European businesses of up to €600 billion, equivalent to 8% of the annual turnover, and a reduction in global greenhouse gas emissions by 2-4% (European Environment Agency, 2015b). In order to reach these eco-efficiency targets, radical innovations are required for the treatment of high-value/high-impact waste streams, such as Waste Electric and Electronic Equipment (WEEE). WEEE, also referred to as “e-waste”, currently is the fastest growing waste stream in the EU, growing at annual rate of 3-5% (Eurostat, 2019a). Whereas there is a high variation among member states in Europe, reuse and repair efficiencies are overall still characterized by relatively low efficiencies in Europe (Eurostat, 2019b).

One of the major reasons for this is that information associated with products is gradually lost after the point of sale (Thomas, Neckel, & Wagner, 1999). Close cooperation of the authors with large OEMs in prior research, such as Philips, also demonstrated that even when the product model is correctly identified it is either not possible or very difficult to retrieve relevant information for reuse, repair and recycling, such as technical drawings, manuals, disassembly instructions, component lists, failure diagnostics, material types used, etc. The reason for this being that all information was mostly not systematically stored in a well-structured manner for this purpose.

Consequently, operators in reuse, repair and recycling companies are either deemed to (1) treat all products of a specific category in the same manner, or to (2) become specialists with the required knowledge on properties and differences of different product brands and models or to (3) browse the internet for information and instructions. While recycling centers mainly opt to treat all products of a product category in a similar manner or to make only minor differentiations among generic product features, organizations focusing on reuse and repair were found to often rely on people with adequate knowledge and experience, freely available product information and reuse and repair instructions on various websites, such as www.ifixit.com.

However, recently developed computer vision architectures can offer solutions to automatically identify the design or model of products. Therefore, the University of Leuven – KU Leuven recently started working on the development of an application to allow the exploration, combination and demonstration of the applicability of computer vision systems for the sector of reuse, repair and recycling. This research is part of the Smart Re project funded by the Flemish waste agency OVAM under the 'Vlaanderen Circulair' project call for circular cities and entrepreneurship.

For this the ongoing research investigates the applicability and the integration of prior developed computer vision algorithms to identify products and product features using a computer or tablet with an external or integrated (web)cam. Initial focus is on the detection and identification of barcodes and the brand and model number mentioned on the product labels. Asides from identifying the product model it is of equal importance to also make useful information available for reuse, repair of recycling operations. For this purpose, existing algorithms and database structures are explored to easily retrieve product information from different sources. It is the objective that the developed software, user interfaces and databases will be integrated in an application which will be tested and evaluated in close cooperation with the network of reuse and repair centers of Flanders 'De Kringwinkels' and by Belgian's largest recycling company Galloo.

In the initial phase of development of this application it is of importance to obtain a good overview of, on the one hand, the opportunities and challenges and, on the other hand, the desired functionalities of this application. In addition, to define priorities in the development of the envisaged application it is important to investigate which components, such as computer vision algorithms, are already available and to understand the required efforts to integrate these components in the envisaged application. For this reason, multiple plant visits and discussions with different actors of the reuse, repair and recycling sector have been performed. In addition, initial experiments have been carried out to evaluate the applicability of different computer vision algorithms for the envisaged application, on which is reported in this article.

Challenges and opportunities

During various discussions with reuse, repair and recycling centers, the following challenges and opportunities of relevance for the envisaged developments were identified:

- The increasing turnover of staff in reuse, repair and recycling centers increases also the urge to properly document acquired knowledge to prevent knowledge to be lost every time someone leaves the organization.
- A significant share of the people working in reuse and repair centers are employed by the social service department of the Flemish government. As a result, there is an increasing importance for tools to education of these employees.
- There is an increasing difference in capabilities of the employees of reuse, repair and recycling centers in consequence of legislative and social evolution both on regional and international level, as well as the refugee crisis that Europe is currently facing. Consequently, it is of importance to find means to improve the cooperation amongst these employees to simulate the sharing of knowledge regardless of cultural and language barriers, for example between a well-educated refugee and a lower educated employee.
- New legislation for protected working environments increases the need to find tools to adapt the work to the individual needs or limitations of the employees, as the inverse is often not feasible (Flemish Department of Work and Social Economy, 2013).
- The increasing complexity of the testing for reuse and the repair of more recent electric and electronic equipment has forced reuse and repair centers to specialize. However, due to the further increasing complexity of these products, several reuse and repair centers are currently considering to limit their scope or to entirely stop their activities. The main reasons mentioned is that either it is not possible to find employees with the required knowledge and experience or that it is no longer possible to train them their selves.
- The current demand already exceeds the offer of second hand or repaired electric and electronic equipment. With the systematically increasing collection targets, this offer and demand could come in better balanced. However, the increasing concern on data security is expected to have a negative effect on the number of IT-

products that will offered to reuse and repair centers. Therefore, there is a need to integrate the required procedures and checks to assure correct data wiping.

- A further evolution in customer behavior is expected, which will force reuse and repair centers to adapt their communication and sales strategies. Several of the interviewed reuse and repair centers already operate an online sales channel. However, the detail of information on these sales channels is today still rather limited and will need to be further improved to meet customer expectations.
- During both discussions with recycling centers and experiments carried out by the authors it was pointed out that a significant share of the waste stream of WEEE were relatively recent products. For example, in an experiment carried out in 2016 at Galloo in Belgium 288 Hard Disk Drives (HDD) from laptops and 94 HDDs from desktop PCs were collected. For all these HDDs the year of production was retrieved from the label. This experiment showed that more than 15% of the laptop and desktop computers encountered in the WEEE were less than 5 year old, as shown in Figure 1. Prior research also confirmed these findings for whitegoods and demonstrated that 10% of all discarded washing machines were less than 5 year old (Prakash, Dehoust, Gsell, & Schleicher, 2016). This indicates that still a substantial number of products in the WEEE that is currently send for material recycling can either be reused or repaired, or could be disassembled for components that could be used for others repairs.

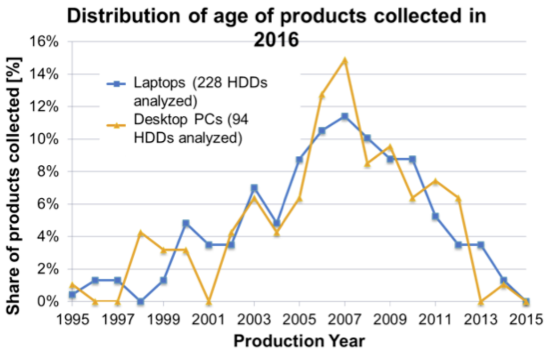

Figure 1. Year of production of HDDs from laptops and desktop computers in WEEE.

Desired functionalities

Since reuse and repair centers face different challenges, they also have, sometimes the same, but also very different advantages of tools for the efficient retrieval of product information and instructions.

For reuse centers, the following opportunities and, hence, the desired functionalities of the envisaged application were identified: (1) making manuals and checklists available for the testing of the correct functioning of the product, (2) making the original sales price and past sales experiences for similar or the same second hand products available, for example past sales price and shell time, to allow a more correct price setting and (3) make correct product information available to correctly identify the customer. For example, the energy class of the second hand product is considered to be important information to inform customers on the intensity with which a second hand product can be used without being economically disadvantageous compared to a similar new product.

For repair centers the desired functionalities also comprise these of a reuse center when the repair is not commissioned by the owner of the product, but repaired products are sold to a new customer. In addition, an application can support the different steps in a repair process by: (1) supporting the preparation of a quotation, for example by making estimations on the expected time required for repair and cost of spare parts for prior repairs of similar or the same product. (2) The identification of the failure can also be facilitated by either or both making failure diagnostics or failure probabilities available for the person performing the repair. (3) After failure diagnostics it is of importance to have the correct repair instructions at hand to guide the required handlings, such as disassembly, cleaning and reassembling. (4) Spare parts are commonly searched online. However, finding the suited spare parts, verifying that it is the correct spare part and comparing different options and prices, can be time consuming. Therefore, it is of value to facilitate the linking of a product model with suited spare parts.

For recycling centers the main value is considered to be (1) in supporting the identification of products that can be either reused entirely or of specific components that could be reused or used for repair or upgrading, for example RAM memory and HDDs could be recovered to upgrade the working memory and

Figure 2. Results of analysis by Tesseract OCR software of a label from a Philips LCD TV.

the data storage of older computers. Another possible use is (2) the support of dismantling activities, in which product specific instructions could be provided to vary the depth of disassembly depending on the ease of disassembly and value to be recovered. In addition, (3) information on the type of materials used, such as the type of plastics used for the housing components, could also be of value to support the sorting and, subsequent, recycling of the dismantled components.
Asides from supporting the process of reuse, repair and recycling it is always also of importance to support the reporting both internally and externally, for example for compliance with national legislation. For internal reporting, many opportunities exist to stimulate the employees either financially or by better quantification on how they contribute to both economic and environmental targets.

Initial computer vision experiments

Whereas many opportunities lie in making more (correct) product information and instructions available, the first challenges is the correct identification of the product make or model. To speed up the identification of the correct product model the applicability of computer vision techniques is investigated. However, it should be considered that the efficiency and accuracy of any computer vision techniques strongly depends on the quality of the provided image. Therefore, it is of importance to define a suited camera setup. For this two options are considered; either a mobile setup in which the operators moves a camera close to the label of a product and takes an image after verifying the quality of the image or a fixed setup in which an image is gathered from the entire product. In both cases a proper control of the lighting has proven to be of importance, which in case of a mobile setup can be significantly improved by applying a ring light around the camera. For a mobile setup additional advantages are the use of a blue screen which allows to easily crop the product from the full image. In addition, a 3d camera is considered to have significant potential as the geometric shape could also be used to define the product model.
After gathering a qualitative image, the first most evident step is to perform barcode detection, as this is a fast and reliable way to determine the product model. Various software solutions are commercially available to perform barcode detection, as well as open source solutions, such as Zbar (Brown, 2011). Initial experiments with this open source software demonstrated that when a barcode is visible the location, type and content of the barcode can easily be determined for EAN-13 or EAN- 8 barcode (European Article Number of International Article Number), UPC-A or -E (Universal Product Code), Code 128 or 39 and QR Code. However, the speed of detection and success rate for correct identification strongly depends on how the barcode is supplied, as the efficiency is much higher when only a cropped image of the barcode is supplied then when an image containing also other information, such as text, is passed on to the barcode detector.
Initial experiments also demonstrated that there is not always a barcode present or that in some cases the barcode is damaged to the extent that it cannot be decoded. In addition, information from the barcode does not always enables to make a direct link to the product model, as barcodes are also commonly used for service tags, labels of software licenses, etc.

Therefore, it is also valuable to perform Optical Character Recognition (OCR) to read the text from barcodes, which in most cases also contains the product model. Also for OCR, many solutions are available both as commercial software, such as Apose, Asprise, hecksum, Atalasoft, Glyphreader, Abbyy, and as open source software such as Tesseract (Google Open Source, n.d.). In cooperation with industrial partners both the commercial and open source software were compared and substantial differences were found. When the text was correctly cropped and passed on to Tesserect, the results were comparable to those of the best working commercial OCR software. As shown in **Figure 2**, it is technically feasible to extract useful information with the Tesseract OCR software. However, extracting the model number is not always evident, as the model number is not always preceded by 'MODEL NO'. Therefore, it is important to apply different filters to exclude words that don't provide useful information, such as '50/60Hz' and 'WARNING'. In addition, in several cases it was found that some letters were wrongly read, such as a "0" as an "O", which will need either a corrections or a variation of the read model number prior to finding a match.

Based on these findings, the architecture shown in **Figure 3** is proposed. In this architecture the user has a mobile application with which an image of the label is captured, the mobile application will downscale the image resolution and send it to the server. On the server, deep learning computer vision software will be used to segment the labels into images that only contain text or only a barcode, which will be passed to either Tesseract or Zbar. The results from these algorithms will be filtered and afterwards used to find a best match in the database. If the match has a high confidence, the information that has been stored for the identified product model will be passed on to the operator and the operator will be provided the option to correct or add information for the specific product.

Conclusions and future work

In the presented research several challenges faced by reuse, repair and recycling centers have been identified, as well as opportunities on how a software application could support these activities by identifying the product model using state-of-the-art computer vision technologies to retrieve information in a database. A generic architecture for this software has been identified based on initial experiments with open source software for barcode reading and Optical Character Recognition (OCR), which demonstrated great potential of the envisaged application.

In future research, large datasets of images from product labels will be gathered to in first instance train deep learning computer vision software to detect both the location of barcodes and text in an image to segment the image and

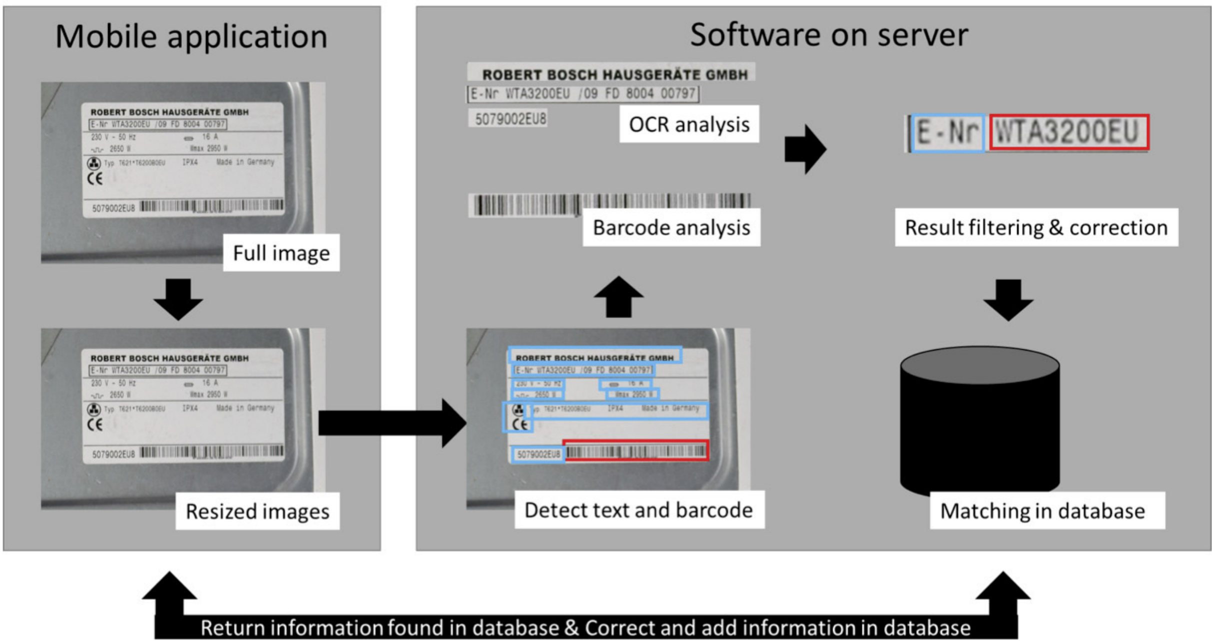

Figure 3. Simplified and initial architecture for reuse, repair and recycling application using computer vision.

improve the efficiency of barcode detection and OCR. Thereafter, the required filters will be developed based on this large set of product labels and software for finding a match in a database will be developed. Finally, experiments will be carried out in close cooperation with reuse, repair and recycling centers to evaluate the robustness of the developed software and to determine which information and instructions have the highest value to be saved and retrieved by the developed application.

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