4th PLATE 2021 Virtual Conference
Limerick, Ireland - 26-28 May 2021

Fostering Collaboration between Reuse, Repair and Recycling Centers for Electric and Electronic Equipment

Wouter Sterkens[a,b], Ellen Bracquené[a], Toon Goedemé[b], Wim Dewulf[a], Jef R. Peeters[a]
a) Department of Mechanical Engineering – KU Leuven, Leuven, Belgium
b) PSI-EAVISE – KU Leuven, Sint-Katelijne-Waver, Belgium

Keywords: Electric and Electronic Equipment; Reuse, Repair and Recycling; Computer Vision; Deep learning Object Character Recognition; Product Identification.

Abstract: When an electronic device fails, treatment procedures and objectives can differ significantly depending on the actor who receives the device. For example, repair facilities generally focus on product reuse and rely on the expertise of employees to select models suitable for repair and subsequent reselling in second-hand stores, while recycling businesses generally focus on bulk processing to recycle raw materials. Even though devices destined for recycling might still qualify for repair or contain valuable/reusable components, there is no method to identify those models quickly in a cost-efficient manner. In addition, tools are lacking that facilitate the registration and retrieval of information on the repairability of specific models or the value of its spare parts. Therefore, an interactive web application has been developed in close collaboration with one of Europe's largest networks of reuse and repair centers. The developed application can be used when performing triage to determine whether to repair or recycle a specific model. A photograph of the device label is uploaded to an online model identification pipeline. The latter recognizes text on the image with deep learning techniques and compares the text with a database to identify the model, allowing for model-specific information and previous repair experiences to be displayed to the user. Thereafter, novel triage and repair information can be registered and stored for later use. In the presented research, the triage and registration procedure is tested at two repair facilities on 97 washing machines. Learnings from the co-development as well as improvements made throughout the experiment on to the interactive interfaces and forms of the application are presented in this article.

Introduction

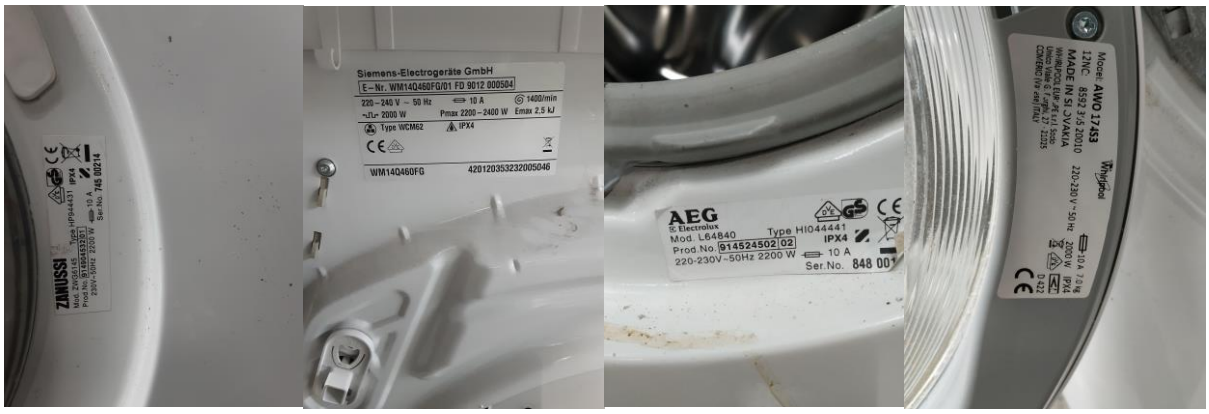
In the European Green Deal initiative, the European Union proposes a strategy towards a sustainable European economy (European Commission, 2019). The electronics sector is identified as one of the major resource-intensive sectors with substantial improvement opportunities to support the transition towards a circular economy. To this end, specific measures will be required to encourage the development of more sustainable Electric and Electronic Equipment (EEE). Among these measures, using digital technologies such as the concept of electronic product passports are proposed to improve the availability of device-specific information which is considered vital for various businesses adopting circular business models. For example, repair businesses often need to identify the type and model of the device to find relevant repair guides and spare part information. Similarly for reuse centers, the retrieval of product information is important to correctly inform customers about the model number, maintenance instructions, and energy label, which are often mandatory details that need to be provided when reselling a device.

For current shredder-based EEE recycling practices, model-specific information is not necessary as various models are jointly treated. However, discussions with different reuse and repair centers in Flanders indicate that the sales of second-hand EEE are limited by the amount of devices than can be sourced for repair and reselling, rather than by costumer demand. Indeed, an annual increase in sales of 1,36% was reported in 2019 by De Kringwinkel, which is located in Flanders, Belgium and is one of Europe's largest networks of reuse and repair centers (HERW!N, 2021). Therefore, great opportunities are to be expected when more potentially repairable products, as well as components frequently required for those repairs, could be sourced from recycling centers. The main bottlenecks to implement those opportunities are expected to be the cost-efficiency of both the triage and the repair itself, for which EEE repair and reuse facilities

generally focus on training personnel to become experts for specific types of electronic products (e.g. only kitchen appliances, laptops or televisions).
This need for experts to perform triage and repair reduces the economic viability of these activities, limits the scalability, and consequently hinders reaching the circular economy targets put forward by the European Commission. Additionally, the existing knowledge of experts can only be transferred locally. As a result, collaboration between (waste) EEE collection points and repair and reuse centers is often limited to certain regions and for certain high-value waste streams, such as large household appliances and ICT.
The hypothesis is that performing model identification during recycling and repair procedures is fundamental to handle these challenges. By identifying the model of a device, relevant model-specific information can be consulted to perform decision making whether to attempt to repair or whether to discard a device for recycling. In addition, triage is also affected by other factors. The reason behind the malfunctioning of specific product models can often be accredited to a small number of recurring issues which may or may not be repairable or require expensive or unavailable spare parts. Consequently, it is expected that identifying the model and registering relevant triage and repair information would highlight these issues. The resulting quantitative information on the repairability of certain devices could lead to valuable insights to optimize both triage and repair activities.
However, to initiate model identification and subsequent registration of triage and repair by repair centers, the procedure would need to be seamlessly adopted into existing manual triage and repair practices. Therefore, an interactive web application which implements state-of-the-art deep learning text extraction techniques for device identification has been developed together with a user-friendly interface that allows for model information to be displayed and for repair and triage information to be structurally registered.
The underlying methodology and reasoning that lead to the various decisions made during the development is explained in the second chapter. The results of initial tests of the developed RepairApp at two repair centers for the repair of washing machines is presented in the third chapter along with the feedback obtained and lessons learned during pilot testing.

Materials and Methods

At the outset of the project, a fully functional product identification prototype was developed based on open-sourced libraries. In this prototype, devices were identified by extracting text from an image of the device label, similar to the images shown in Figure 1**Error! Reference source not found.**. Hand-tuned filters were used to attempt identification of the model number from the extracted text, after which this attempt was compared with a database. This database was built from information which was registered during prior analyses. The initial prototype was developed as a python package running on a personal computer with the aim of determining minimum viable product (MPV) requirements for the eventual RepairApp in collaboration with employees of De Kringwinkel.



(a) **(b)** **(c)** **(d)**

Figure 1. Images of washing machines labels captured at a repair center to perform model identification

Various functionalities that could potentially be provided by the RepairApp were discussed and ranked by assessing the added value for the repair activities on the one hand and the ease of implementation on the other hand. Washing machines were selected as a case study because of their frequent repair, the large demand for second-hand devices and relatively high residual value compared to other white goods. The ease of implementation was assessed based on the availability and difficulty to integrate the required algorithms into a mobile application. Based on this discussion, the following functionalities were determined to be incorporated/excluded:

Incorporated functionalities for MVP:

- Product identification procedure.
- Ability to validate the device model from a list of models proposed by the identification procedure.
- Access to the following product data when the model is identified: Model number, brand name, energy efficiency label, water usage, power usage, device dimensions, device weight, maximum rotation speed, availability of a separate eco-mode, a link to a device manual, and the expected target price to resell the device.
- Registering whether an attempt was made to repair the device or whether the device was discarded for recycling (triage) and registering repair information in an interactive form which can be updated by different users.
- The triage of washing machines, the actual repair, the registration of information and preparation for device reselling is all performed at different times and possibly by multiple people. Therefore, users are able to consult a list of recently registered devices.

Excluded functionalities due to limited added value:

- No translation of the application itself nor of the recorded information is planned as supporting non-native-speaking employees to learn Dutch is one of the social objectives of De Kringwinkel.
- Due to the complexity of compliance with the European General Data Protection Regulation (GDPR), no account system is used. A name or alias is only requested during registration so users themselves can keep track of ongoing repairs.
- Open access: access to web application is also kept private as the used data was only made available for testing with De Kringwinkel.

Functionalities excluded due to complexity of implementation:

- A flat-file database structure is adopted. Registered information is bound to a single model number. Potential relevance of specific information for similar model numbers or an entire series is not considered.

Based on the MVP requirements, a web application, named the ‘RepairApp’, was developed. The number of users can easily be scaled up and any type of electronic device with internet and browser access, including tablets and mobile phones running any operating system (including Android and Apple iOS), can be used to interact with users. The development of the RepairApp was performed in collaboration with Kunlabora, a software development company located in Leuven, Belgium (Kunlabora, 2021), and was developed using Amazon Web Services (AWS, 2021).
In the RepairApp, users are first requested to capture an image of the device label (examples of uploaded images shown in Figure 1). Subsequently, the image is uploaded to an online product identification pipeline, where state-of-the-art deep learning image text extraction techniques are utilized to extract text from the image. For this step, multiple deep learning text detection and recognition architectures were evaluated on a dataset of 200 washing machine labels (Du et al., 2020; Liao et al., 2018, 2019; Shi et al., 2017). Finally, the Google Vision text recognition service was selected for integration as it extracted text with the least matching errors between the ground truth model number and the extracted text (Sterkens et al., 2020). The extracted text is then compared with a model database in order to identify the device. To perform this comparison, the Levenshtein distance scoring technique was implemented (Levenshtein, 1966). The matching procedure was made available as an online service by using the AWS Elasticsearch Service (AWS, 2021b).
From this pipeline, a ranking of multiple potential model numbers are proposed to the user. Subsequently, product information, such as the model number, energy efficiency class,

year of introduction and power/water use as well as previously registered repair instructions can be requested from the database and displayed in the RepairApp. The user has the possibility to register triage and repair information with the developed interfaces and forms after which this information will be uploaded to the DynamoDB databases used by the application (AWS, 2021a).
An initial version of the app was tested in two repair facilities for washing machines of De Kringwinkel in January 2021. To test the application, a Samsung Galaxy Tab A10 tablet was provided to both facilities. The facilities were also visited on average once every three weeks to provide training, to solve various issues which were encountered during the experiment, and to gather feedback for improvements.

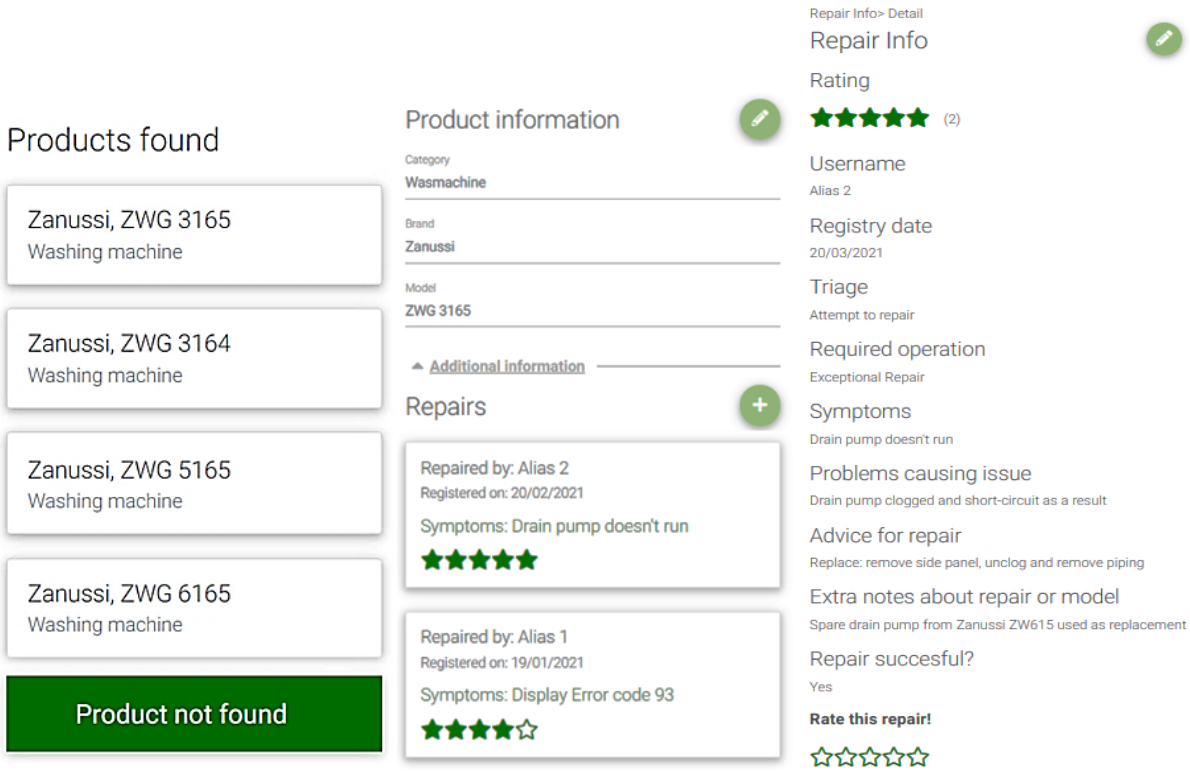
Results & discussion

In order to link the registered repairs to a model, a database was developed by merging washings machine data made available by the data analytics company GFK with records of washing machines previously sold by De Kringwinkel. An overview of the resulting database is displayed in **Error! Reference source not found.**. The main body of the database consisted of information provided by GFK, as in this database, products were already registered according to their model number. 177 unique brands are listed in the GFK database.

Property	Amount registered	Data Source
Model number	10194	GFK
Brand name	10194	GFK
Energy label	10194	GFK
Device dimensions	10194	GFK
Rotations per minute	10194	GFK
Water usage	5727	GFK
Energy usage	5632	GFK
Device weight	3189	GFK
Link to manual	602	De Kringwinkel
Target reselling price	552	De Kringwinkel

Table 1. Overview of model information available in RepairApp database.

In addition, 602 links to a device manual, and 552 target prices to resell the model in second-hand stores were extracted from the database provided by de Kringwinkel and attached to the corresponding model. This information was attached by matching the accompanying model number with the GFK data. Originally, 8995 records of resold devices were made available by De Kringwinkel, of which 1025 and 7632 records contained a link to a device manual and target price respectively. However, the model number was often registered incorrectly or incompletely, resulting in only 58% of the manual links, and 14% of the target prices to be attached to the GFK database. A common mistake in the historic data concerned registration of the series the model number, which made linking the data, as well retrieving the information later on no longer possible.
After an image has been captured by the user and posted to the server to find possible matches, the 30 models with the highest matching score are proposed by the model identification pipeline and displayed to the user as shown in Figure 2a. This allows for the correct model to be identified even when the recognized text is not fully identical to the ground truth. In this overview, only the brand and model number are displayed to avoid confusion during the selection procedure and to assure that the operator double-checks the correctness of the identified model number. With the current implementation, it takes 5 seconds on average to process an image of a label and propose a list of model numbers. If no matching model number is found, users should register the device as new model by using the “product not found” option. This procedure must be followed, even if there is only a slight difference between the proposed model number and the ground truth. This way, additional model numbers and related information are correctly added to the product database, resulting in more correct model number proposals by the pipeline over time.



(a) **(b)** **(c)**

Figure 2. Examples of screens displayed by the RepairApp during the product identification procedure translated from Dutch to English for the sake of this publication. (a) Models proposed by the identification procedure. (b) Model information and previous repairs displayed after selecting a model. (c) Additional information on previously registered repair.

After selecting the correct model number or registering a new device, product information and previously entered repairs are displayed as shown in Figure 2b. Additional product information is shown when pressing the "additional data" marker, as shown in Figure 3. This product information is usually consulted and updated by users when preparing the device for reselling. Below the product information, previously registered repairs are displayed, ranked according to average star-rating the repair has obtained over time. This user-based ranking method was selected to assure that the most valuable repair information is more easily found on the one hand and because of the ease of implementation on the other. Along with the rating, the alias of the person that registered the repair, the date of registration, and the described symptoms of the issue are displayed to allow users to easily find relevant previous registries with similar symptoms. When clicking on a prior repair, more information on the underlying problem and how it was solved is displayed as shown in Figure 2c. Cases where the repair was not attempted or unsuccessful will also be displayed if relevant.

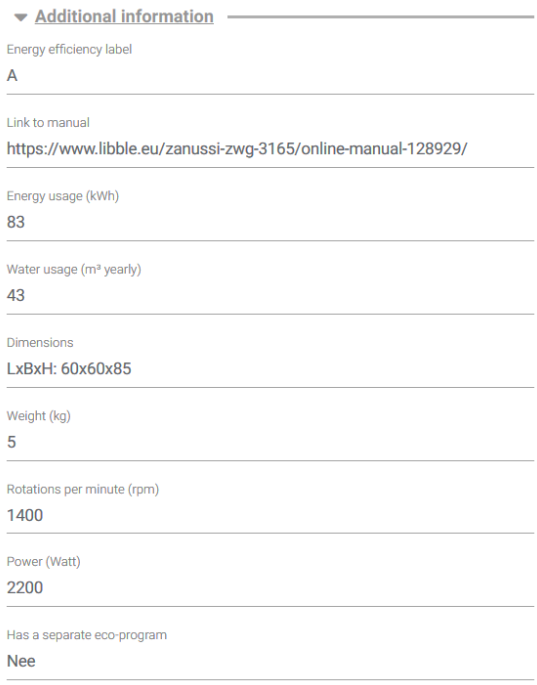


Figure 3. Product information which can be consulted and edited in addition to the fields shown in Figure 2b, translated from Dutch to English.

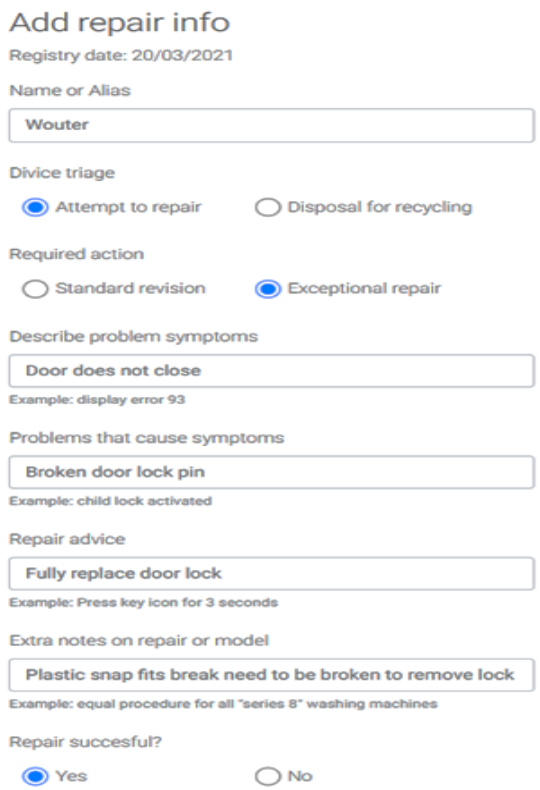


Figure 4. Form displayed to user when a new individual device is registered.

This information on previous repairs can all be consulted to perform the next step, the registry of a new device as shown in Figure 4. Regardless of the decision made, users are requested to perform the complete procedure for every new device arriving in the facility, in order to gather data on the triage of specific model numbers. Users can select whether an attempt was made to repair the device, or whether the device was discarded for recycling. In the former case, the remainder of the form is filled out afterwards. In the latter case, users are only asked to enter why the device was discarded for recycling.
When an attempt to repair is performed, users are solely requested to enter repair information for unusual repairs. This feature was included in a later version of the RepairApp. Standard revision procedures are performed for washing machines by De Kringwinkel, for example the replacement of shock absorbers and carbon brushes. The amount of added value for De Kringwinkel employees to describe these repairs is limited. As a result, users rather focus on properly documenting abnormal repairs, as this information is most useful to share between users and facilities. Nevertheless, motivating some personnel from De Kringwinkel to use the app was found to be challenging. Several experienced employees were averse to share information on challenging repairs with the outside world. Analysis of the initial registries showed that information was incorrect or very limited in most cases. To attempt to improve this, the user interface of the entry fields were adapted multiple times in cooperation with team leaders from De Kringwinkel and examples were added for every field. However, some operators still had difficulties to enter a proper description, which is assumed to be mainly due to limited Dutch language skills and fear of entering information incorrectly. To overcome these issues, the overall objective of the RepairApp and the sole purpose of the alias to retrieve past repairs was better explained. In addition, a feature was created for the workshop team leader to review and edit the repair information entered by adding the afore mentioned option to consult a list of recent repairs.

	Attempt to repair		**Discarded for recycling**
	82%		18%
Standard revision	**Unusual repair**		
73%	27%		
	Details described	**Details not described**	
	88%	22%	

Table 2. The rate of devices registered for repair/recycling with the RepairApp, the rate of repair registered as unusual, and the rate of unusual repairs with details entered.

To this date, 97 devices were registered using the repair app over the course of four months, but with an accumulated work time of approximately two months. The resulting registration rates as of now are displayed in **Error! Reference source not found.**. Of the registered attempts for repair, 91% were selected as successfully completed. Notably, 27% of washing machines were registered as requiring an unusual repair, but of those registries, the fields for describing details on the repair were not filled out by users 22% of the time. However, the amount of collected data to this day is too limited to be able to draw conclusions. After the afore mentioned improvement measures were taken, recent registries are made more complete and the use of the RepairApp is better welcomed by the

users. Hence, data collection can be intensified in view of further assessing the effectiveness of the approach.

Conclusions

Various benefits can be found in more systematic registration of model-specific product information and information relevant for repair. To facilitate this, the web application, named the 'RepairApp' is developed in the presented research. It allows users to identify a product model by capturing an image of a product label and using deep learning text extraction techniques to detect the product model number. Based on this product identification, relevant information can be retrieved from a database. Pilot tests were performed at two repair centers for washing machines and 97 devices were registered using the RepairApp. Various challenges were encountered and opportunities were identified to improve the application interfaces and forms. Nevertheless, challenges remain to better inform and train users of the application and promote the use of the RepairApp, whereas the value of using the application is expected to grow along with the content of the database and hence, the relevance of the information that can be accessed using the RepairApp. During pilot testing, the application was used in parallel with the current paper-based registration tools. Therefore, future work will investigate how the RepairApp could be further integrated and replace and/or aid current registration procedures.

In future research, the model identification pipeline will be evaluated and optimized with the data that is being generated in terms of the share of recognized products. Furthermore, the applicability of similar product model identification techniques in recycling centers will be investigated to evaluate opportunities for collaboration between repair and recycling centers. Devices frequently repaired using the RepairApp will be compared with models identified at the recycling facility with the ambition to reuse devices or recover components from the recycling facility. Collaboration has been established for this evaluation and approximately 1000 images have been gathered in a recycling facility during initial experiments.

Acknowledgments

This research is performed as a part of the Smart-re project, which is supported Vlaanderen Circulair.

References

AWS. (2021a). *Amazon DynamoDB, NoSQL Key-Value Database, Amazon Web Services*. https://aws.amazon.com/dynamodb/

AWS. (2021b). *Amazon Elasticsearch Service, Amazon Web Services*. https://aws.amazon.com/elasticsearch-service/

AWS. (2021c). *Amazon Web Services (AWS)—Cloud Computing Services*. https://aws.amazon.com/

Du, Y., Li, C., Guo, R., Yin, X., Liu, W., Zhou, J., Bai, Y., Yu, Z., Yang, Y., Dang, Q., & Wang, H. (2020). PP-OCR: A Practical Ultra Lightweight OCR System. *ArXiv:2009.09941 [Cs]*. http://arxiv.org/abs/2009.09941

European Commission. (2019). *The European Green Deal* (COM/2019/640 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:640:FIN

HERW!N. (2021). *Feiten en cijfers 2019*. Herwin. https://static1.squarespace.com/static/5ce5028b5d4c700001e75fdd/t/5f96e432b37e024706049369/1603724338329/Herwin_Factsheet_Feiten-Cijfers_2019_Druk.pdf

Kunlabora. (2021). *Kunlabora—Software solutions. Custom built. Made together.* https://www.kunlabora.be/

Levenshtein, V. I. (1966). *Binary codes capable of correcting deletions, insertions, and reversals*.

Liao, M., Shi, B., & Bai, X. (2018). TextBoxes++: A Single-Shot Oriented Scene Text Detector. *IEEE Transactions on Image Processing*, *27*(8), 3676–3690. https://doi.org/10.1109/TIP.2018.2825107

Liao, M., Wan, Z., Yao, C., Chen, K., & Bai, X. (2019). Real-time Scene Text Detection with Differentiable Binarization. *ArXiv:1911.08947 [Cs]*. http://arxiv.org/abs/1911.08947

Shi, B., Bai, X., & Belongie, S. (2017). Detecting Oriented Text in Natural Images by Linking Segments. *ArXiv:1703.06520 [Cs]*. http://arxiv.org/abs/1703.06520

Sterkens, W., Diaz Romero, D., Goedemé, T., Dewulf, W., & Peeters, J. (2020). A Deep Learning Product Label Identification Pipeline for Recycling and Repair. *Proceedings Electronics Goes Green 2020*, 492–499. https://online.electronicsgoesgreen.org/wp-content/uploads/2020/10/Proceedings_EGG2020_v2.pdf#page=492