Robotic System Design and Development for Automated Dismantling of PCB Waste

Ioan Doroftei[1], Daniel Chirita[1], Carlos Pascal[1],
Ciprian Stamate[1], Stelian Cazan[1], Adrian Burlacu[1*]

[1]Gheorghe Asachi Technical Univeristy of Iasi, Romania
[*] corresponding author aburlacu@ac.tuiasi.ro

Abstract

Purpose: the mass electronics sector is one of the most critical source of waste, in terms of volume and content with dangerous effects on the environment. Automated and accurate dismantling systems can improve the outcome of recycling.

Design/methodology/approach: - Following a short introduction, the paper details the implementation layout and highlights the advantages of using a custom architecture for automated dismantling of PCB waste.

Findings - currently, the amount of electronic waste is impressive while manual dismantling is a very common and non-efficient approach. Designing an automatic procedure that can be replicated, is one of the task for efficient electronic waste recovery. This paper presents an architecture for advanced recovery of particular waste materials from computer and telecommunications equipment. The automated mechanical dismantling scheme is built on an eye-to-hand approach using a robotic system and a custom tool.

Originality - the proposed dismantling scheme uses data provided by an artificial vision system to guide a custom tool attached to the last link of a six degrees of freedom manipulator robot. The design of the custom tool includes a programmable screwdriver combined with an innovative rotary dismantling element.

Keywords Electronic waste, eye-to-hand robotic system, custom dismantling tool.

Paper type Research paper

1 Introduction

Electronic waste or e-waste represent about 3-5% of the general waste worldwide a year. This can be quantified as about 40 or even 50 million tons a year. The multitude of electronics devices generates one of the most important sources of waste, both in volume and content with dangerous effects on the environment (Perez-Belis et al. 2015, Zeng & Li 2016).

Among e-waste components, printed circuits boards (PCBs) are the most valuable part of an Electrical and Electronic Equipment (EEEs). These boards contain a lot of reusable parts, valuable metals but also dangerous and hazardous components. This is why the nowadays studies related to material recovery from e-waste are very detailed and extensive. On one side, reusable elements and precious metals need to be recovered and, on the other side, the recycling procedure for environment protection has to be accomplished properly.

Currently, the amount of electronic waste is impressive while manual dismantling is a very common and non-efficient approach (Achillas et al. 2013). In (Park et al. 2015), it is presented a newly-designed and automatic EC disassembling apparatus, that includes an IR heater and steel brushes. All the experiments in (Park et al. 2015) were accomplished using laptops PCBs. This device proved to be ineffective for screws and high energy consumer.

The main goal in (Kopacek & Kopacek 2015) is recovering precious metals from PCBs. In order to avoid the full destruction of the baseboard, a semi-automatic plant is presented. This cell consists of a transportation system, a vision system and stations that provide heating and are useful for de-soldering. The main disadvantage here is that the feeding and removing are done manually. Another disadvantage consists in the size of the heating device, whose size is limited. This thermal system is very complex from the point of view of control engineering. High temperatures for de-soldering can also affect some components of the board.

An extended analysis on technologies used in electronic waste recycling is presented in (Rocchetti et al. 2018). This work includes information regarding the contribution of a consistent number of patents. Based on this comprehensive overview, we can conclude that currently, in many countries the proposed reduction of waste resulted from PCBs are in a research phase, with no technological routine that can be easily replicated.

Robots are playing a growing role in recycling and product disassembly. The key factor is to gain research results that can be further put into practice in an intuitive manner (Bogue 2019). For this, we propose a proof of concept dismantling scheme based on a robotic system equipped with a custom tool. The custom tool is designed to dismantle cylindrical aluminum electrolytic capacitors. In comparison with state of the art, the proposed system will automatically dismantle the capacitors while protecting the other remaining electronic waste. The paper presents the details of the dismantling scheme design in section 2, while the implementation details are revealed in section 3. The experimental results are presented in section 4, while the conclusions are drawn in section 5.

2 Dismantling scheme design

The goal of the current research is to design a eye-to-hand architecture aimed to improve the WPCB reduction before the chemical phase. The mechanical dismantling phase is set to remove elements of the following categories: batteries, aluminum sinks, capacitors, screws (figure 1). The chemical phase is set to take out all exposed metallic parts together with the electrochemical lixiviants regeneration and the partial electrodeposition of the dissolved metals.

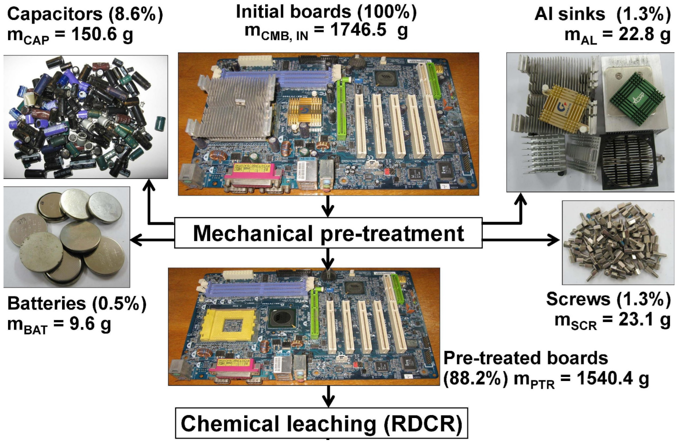

Figure 1: Flowchart of the semi-automated dismantling process (Dorneanu 2017)

Different problems can be avoided by applying mechanical dismantling (Kopacek & Kopacek 2015):

- risk of explosion induced by the highly reactive interior of the Li batteries cams in contact with the leaching substances;

- risk of leaching substances to induce reactions with highly toxic polychloride-biphenyls presented in many cylindrical aluminum electrolytic capacitors;

- increased total time of leaching due to screws with high thickness;

- unjustified consumption of high quantities of leaching agent for the aluminum dissolution induced by the small commercial value of aluminum and the difficulty of aluminum recovery from the resulting substances;

A close analysis on WPCB reveals that E – ATX, ATX, Micro ATX and mini ATX boards are the most used types for computers. Depending on the size, depth and the pins' size of each capacitor, six classes for capacitors framing were defined. A thorough investigation has been accomplished regarding the heights, constitution, diameters and materials capacitors are made of (Stamate et al. 2015).

The proposed dismantling architecture includes an eye-to-hand artificial vision system with depth capabilities, a six degrees of freedom manipulator robot and a custom tool. A centralized computational system is used to: run the 3D position detection algorithms, communication with the robot's controller and capacitors extraction.

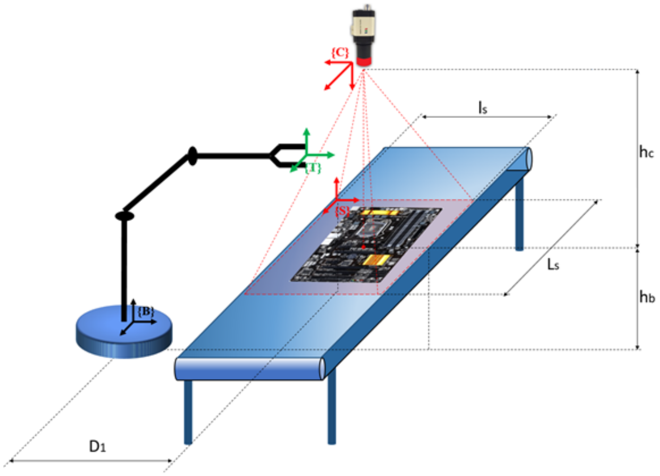

Figure 2: Dismantling scheme design

The components for the proposed design are the following:

- small, powerful and fast 6 – axes robot with a pay load of 6 kg and a 0.81 reach;
- a clamping system for a wider variety of PCB types and a conical pine system with fixing elements;
- a custom pipeline for visual analysis including: image and depth acquisition, image processing and predefined objects identification, plus a lighting source with filters for the uniform dispersion of the light;
- an originally designed rotary tool for components dismantling, which includes a saw teeth type extraction tool and a sensor controlling the tool's triggering and the drill's rotation;
- a centralized computational system is used to: run the 3D position detection algorithms, communication with the robot's controller and capacitors extraction;
- vacuum facilities for capacitor removal.

Currently, the proposed dismantling scheme was designed for cylindrical capacitors and solid dielectric capacitors, however the architecture can be easily customized for other components. Next we detail each component used in implementation.

3 Architecture implementation

3.1 Robotic system

The dismantling procedure is executed by a six degrees of freedom robot with a custom tool attached on the last link. For our application the chosen robotic system is a ABB 140 (figure 3). This industrial robot is a six axis multipurpose robot that handles payload of 6 kg, with long reach (810 mm).

Figure 3: Robotic system

The IRB 140 is versatile and can be floor mounted or inverted. The mechanical arms are completely IP67 standard protected, making it easy to integrate in and suitable for a multitude of applications.

3.2 Artificial vision system

The proposed architecture is built on a eye-to-hand principle. To cope with the challenges induced by data exchange between the visual system and the robotic system, the architecture uses a stereo vision camera and a custom built algorithm for capacitor detection.

For the proposed architecture we chose the ZED stereo system. A comprehensive overview of the main features for the ZED are discussed in (Ortiz et al. 2018). This device is built on 2K stereo cameras that include dual 4MP RGB sensors. The field of view of the stereo system is of 110° and can stream WVGA uncompressed video at a rate up to 100 FPS. The connectivity with the computing system can be done via USB 3.0, also being compatible with USB 2.0. Side-by-side Left and right frames are synchronized and streamed as a single uncompressed video. The on-board ISP (Image Signal Processor) can be tuned for several configurations parameters such as resolution, brightness, contrast, saturation. These parameters can be adjusted through the Software Development Kit (SDK) provided by the manufacturer. Among advantages, the

ZED stereo systems is designed in a compact structure and reduced size (fig. 4), which makes it more viable for industrial applications in comparison to other stereo systems.

Stereo rectification is the process in which two stereo images are corrected, so that, it appears that they had been acquired by two cameras with row-aligned image planes. This step facilitates the stereo disparity estimation, a fundamental process prior to the estimation of the depth map. The ZED stereo system is calibrated by the manufacturer, these calibration parameters can also be optimized using self-calibration option available in the SDK to aligned images after rectification process.

Once the acquisition system is set, the illumination conditions must be tuned. This will allow the processing pipeline to output the best results. To ensure high quality RGB-D acquisition, a custom light source was built. This allows for uniform distribution of light in the acquisition process.

The image processing pipeline is composed from different steps that improve the image quality and detect the locations with the highest probability to be capacitors. First, the color image is transformed to gray. Next, the gray levels distribution is modified by contrast adjustment. This allows for a better identification of the variations in image function. These variations, the edges, are recovered via the application of the Canny detector, with it's inner parameters tuned experimentally (Gonzales & Woods 2018).

The edges map is used as input in the circular Hough transform (Gonzales & Woods 2018). This algorithm computes the most probable positions of circles in the image. Among these positions there are true capacitors and false positives. To filter the results, two criteria are used. The depth is threshold to evaluate positions that are not at the PCB lowest level. The second criterion emerges from a local analysis on the gray level distribution that needs to be bimodal, with a center closer to white.

3.3 Custom tool

Once the 3D positions of the capacitors are computed by the artificial vision pipeline, the dismantling procedure can be employed. The robotic arm should operate for each capacitor under specific values of height and pressure. A custom

Figure 4: Stereo vision sensor

tool is used for extraction. This tool was experimentally designed by using a spindle driven by the programmable screwdriver, with a mobile metallic core. The core is held in a neutral position by two springs positioned in opposite directions. The tool is completed by a chuck attached to the end tool, and a capacitive proximity sensor positioned at the other end (fig. 5).

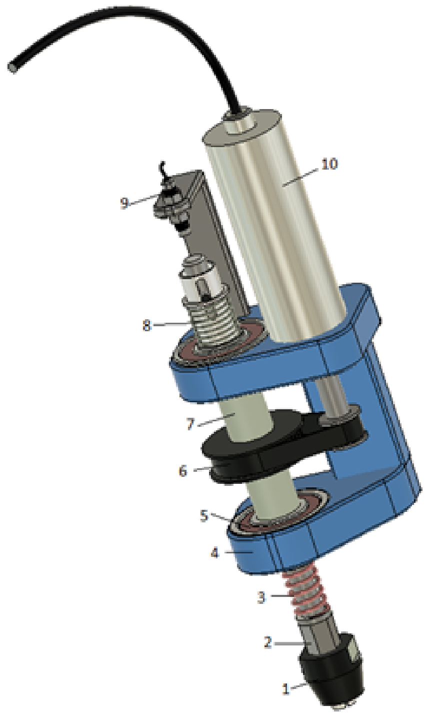

Figure 5: Custom tool for dismantling capacitors: 1-Chuck; 2-Sliding axle with chuck; 3-Fastening spring; 4-Device support; 5- Bearings; 6- Toothed wheel assembly connected with strap; 7- The axis of rotation; 8- Spring to hold the spindle in the work area; 9- Capacitive proximity sensor with possibility of adjustment in the working area; 10-Programmable screwdriver

This device is actuated in the 3D working space by the robotic arm. To dismantle the capacitors, the final tool attached to the screwdriver head will descend on the Z axis to a certain distance imposed on the program. The advantage of the tool's design is that it allows a high precision for positioning on the Z axis.

The tool needs to be positioned above the center of the capacitor to be extracted and lowered until the spindle reaches the aluminum surface. While the robotic arm will advance on the Z axis, the inner part of the tool will slide back as a result of the action of tensed arcs. This elastic pushing force is controlled and its adjustment is made by the position of the capacitive proximity sensor.

The pushing force of the custom tool can be adjusted between 9N and 15N, by pretensioning the spring at the end of the tool. Separately, two resilient pushing forces can be varied until the inductive proximity sensor is activated: the elastic force of the movable spindle holding spring between 35 and 45N and the elastic force of the firm gripping spring between 20 and 30N. The value of the required push force can be adjusted and ranges between 64N and 90N.

3.4 Capacitor dismantling steps

All of the previous systems are integrated in an automated scheme. This scheme is driven by a centralized unit that runs both the 3D capacitors position recovery algorithm and the conversion to the custom tool reference frame. The main steps for the capacitors dismantling are:

- Image and depth acquisition of a PCB board fixed on the work table.
- First a depth threshold is applied, to isolate the 3D area with the highest probability of finding capacitors. This allows for a considerable reduction of flase positive detection.
- Next, the RGB image is processed to recover the most probable positions of the capacitors.
- Once the 3D position in the camera frame is recovered a conversion is done to obtain the capacitors position in the tool frame
- The drive to position is sent to the ABB controller. The moving path includes an intermediary position 50 cm above the work table. This position allows for a vertical descending of the tool when approaching the target.
- In the target configuration the custom tool is activated and the capacitor is dismantled.
- The final step is the removal of the dismantled capacitor via suction.

Next, experimental results are discussed.

4 Experimental results

4.1 From simulation to real implementation

Before putting it into practice, part of the proposed architecture was simulated. More precisely, the simulation allowed for an initial analysis on the behavior of both the robotic system and the custom tool. Using the Robot Studio simulation environment, the working station was designed and multiple path were tested to ensure the feasibility of the proposed motion sequence (fig.6). The motions are carried pose to pose, the implementation being done in RAPID language. Different scenarios were tested and the simulation results allowed for parameters tuning of both robot motion and tool driving.

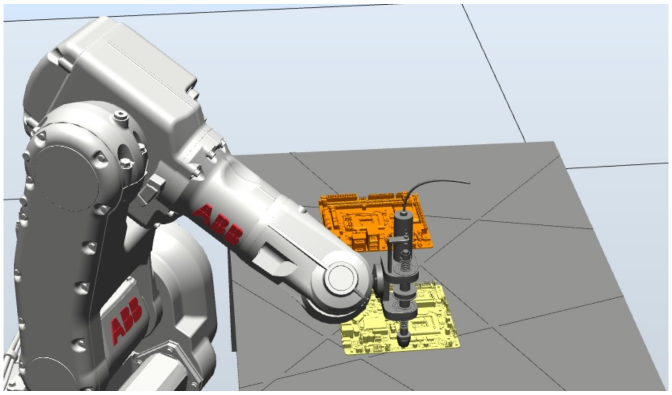

Figure 6: Workstation simulation in Robot Studio

Once the simulations were completed and the tests were considered successful, the next phase was started. In this phase all the subsystems were connected and preliminary tests were carried. Part of the internal parameters of the scheme were experimentally tuned.

A challenging task was the calibration of the custom tool proximity sensor. The role of the proximity sensor is to act as a stopping signal for the robotic arm movement and as a starting signal for the programmable screwdriver, which acts through the mobile spindle multiplication system. A capacitor is dismantled by twisting its link pins by the mobile spindle. This rotates according to the program uploaded in the screwdriver hardware. When the program is finished the motion of the screwdriver is completed and the robotic arm performs a retraction movement from the work area up to a fixed pose. The procedure for removing the dismantled capacitor can be finalized either by vacuum or by accessing a dedicated area. The cycle will be resumed by dismantling another capacitor identified by the artificial vision system.

During the experiments performed with the final design of the tool, it was found that by attaching a mobile spring plate it is possible to empty the final tool. Thus, the robotic arm does not perform an extra displacement maneuver to empty the tool and can resume much faster the cycle to another extraction pose. The optimization of the tool design includes the rod with teeth and a mobile shaft driven by a spring for emptying at the end of extraction. The final design is illustrated in fig. 7.

4.2 Evaluation

To evaluate the results obtained with the proposed dismantling scheme a multi-step evaluation procedure was employed.

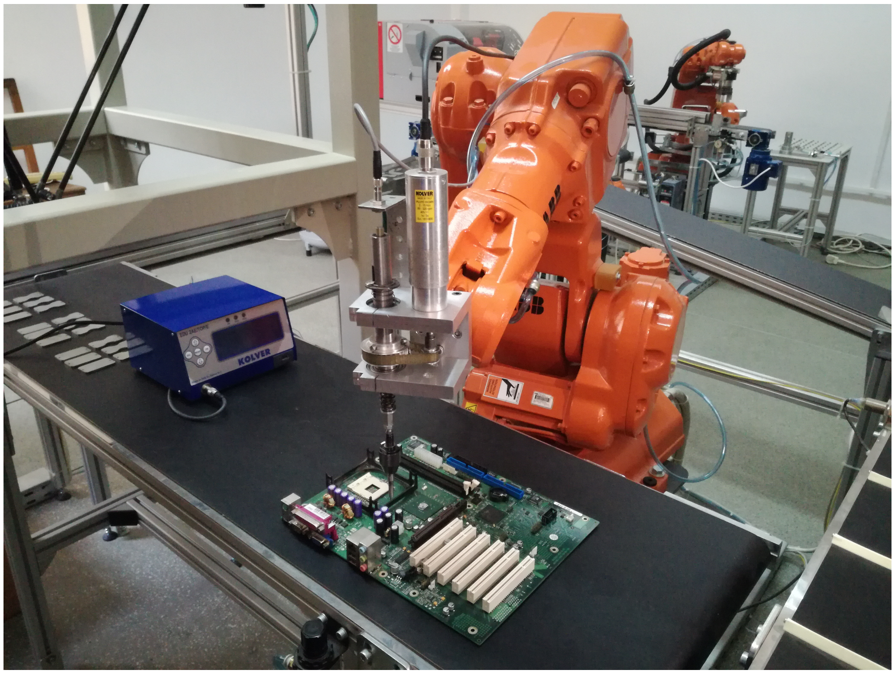

Figure 7: Custom tool attached to robotic system

First, the 3D environment was represented to scale in the simulation software. The robotic dismantling system (manipulator robot and custom tool) is included in the simulation. This allows an initial evaluation on the workspace limitations and on the motions that can be executed.

Once the types of motions that can be executed by the robotic dismantling system were acknowledged, a reliability evaluation of the custom tool was done. For five PCB's, the positions of the capacitors were taught by moving the custom tool manually. After learning the positions, an automated program was executed to analyze the ratio of dismantled capacitors in comparison with their total number. The mean percentage of the experiment was 97%. The failed dismantling were induced by tilted capacitors.

The evaluation of the artificial vision system accuracy to detect correct 3D positions for the capacitors is conducted using a region of interest approach. This type of evaluation compares ground truth data with computational results. The ground truth data was obtained by manually labeling interest areas in PCB images. This phase was done using the image labeler app from Matlab. By comparing the areas detected by the algorithmic pipeline as being capacitors to the ground truth, the true positives mean on the five PCBs was 91%. The false positives indicated by the artificial vision system (red dots in fig.8) were the result of shading in particular areas of the PCB, such as margins or clusters of different types of parts.

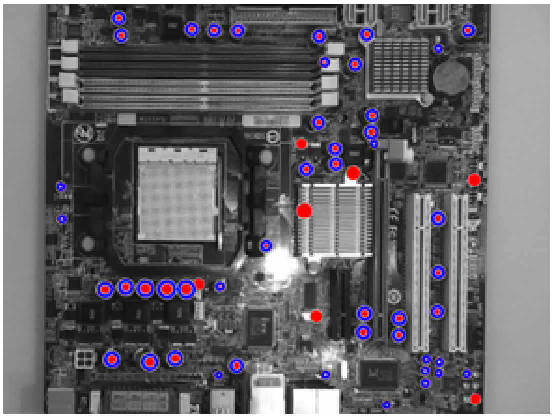

Figure 8: Capacitors identification

These results make us think that a short term improvement is comparing the current approach performances to the performances of a neural classifier. A detection scheme such as You Only Look Once (YOLO) (Redmon et al. 2016) or Aggregate Channel Feature (ACF) (Dollar et al. 2014) are under investigation. Currently we are working on enlarging the training database with different types of PCBs.

The final evaluation was conducted in combining the positions indicated by the artificial vision system with the dismantling motions performed by the custom tool. Regarding efficiency, the current tool can be used to dismantle six classes of capacitors (fig.9).

The eye-to-hand collaboration closes the dismantling process loop. In the current configuration, the proposed dismantling scheme has a mean success rate of over 89%. The performance of the dismantling system was evaluated on twenty PCB.

5 Conclusions

In the current paper we presented a design, simulation and implementation of a eye-to-hand architecture for capacitor dismantling from PCB. The proposed dismantling scheme uses data provided by an artificial vision system to guide a custom tool attached to the last link of a six degrees of freedom manipulator robot. The design of the custom tool includes a programmable screwdriver combined with an innovative rotary dismantling element.

The dismantling system was first simulated and then implemented. Before putting it into practice, an extensive evaluation was conducted on each component. This allowed for internal parameters experimental tuning of each component. The dismantling scheme was tested on automated mode and the experimental results showed good results for six classes of capacitors. The proposed scheme will be further improved to cope with the situations were it failed

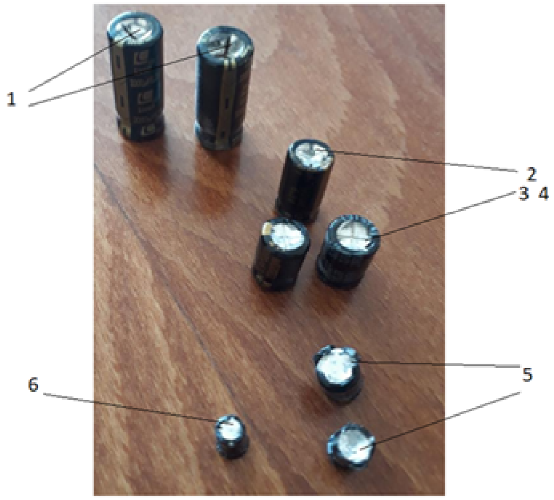

Figure 9: Classes of capacitors removed by the custom tool

in either detecting or dismantling a capacitor.

Future work will imply the use of artificial neural networks classifiers to improve the detection rate of the capacitors. Also, the custom tool will be upgraded to allow more classes of capacitors to be dismantled.

Acknowledgment

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