

Dismantling strategy for capacitors placed on printed circuits boards: challenges and preliminary results

S Cazan¹, D Chirita¹, C Stamate¹, D Irimia², A Burlacu³ and I Doroftei^{1*}

¹Department of Mechanical Engineering, Mechatronics and Robotics, “Gheorghe Asachi” Technical University of Iasi, Iasi, Romania

²Department of Energy Utilisation, Electrical Drives and Industrial Automation, “Gheorghe Asachi” Technical University of Iasi, Iasi, Romania

³Department of Automation Control and Applied Informatics, “Gheorghe Asachi” Technical University of Iasi, Iasi, Romania

*E-mail: idorofte@tuiasi.ro

Abstract. The present paper describes the challenges and preliminary results obtained during the design and implementation of a disassembly system for capacitors placed on printed circuits boards. This research is included in an attempt to reduce the impact of the electronic waste. The proposed architecture includes a six axis multipurpose industrial robot, dedicated sensors and a custom built tool. An originally designed rotary tool, with a specific type of drill bit, was used to dismantle each capacitor on the board. A sensor triggers the tool for the drill rotation when the perforation is accomplished accordingly, so that the friction force is big enough to initiate the dismantling procedure. Using the rotation movement of the drill, at a calculated number of rotations, the capacitors are successfully dismantled from the printed circuits board. An artificial vision system composed from a stereo camera and an image-processing algorithm, provides data with regard to the position of each capacitor on the printed circuit board. A vacuum cleaner was integrated in the scheme to recover the capacitors after dismantling. The scheme design was perpetually optimized using dedicated simulation software. Also, preliminary results obtained on the physical system underline the potential advantages of the proposed approach.

1. Introduction

Many international institutions raised the issue of environmental protection and a proper and effective exploitation of natural resources. This is why recycling policies are enacted at the state or local level, [1]. Regarding e – waste components, there are studies that affirm that about 50 million tons a year of the total amount of waste have electronic provenience. Among e – waste components, printed circuit boards are the most precious and most valued components. There are different stages of materials recovery from printed circuit boards. Before the leaching process [2, 3] for precious metals recovery, another required operation is needed. This procedure consists of printed circuit boards’ components disassembly and dismantling, [4]. While different old procedures neglect the aspect of PCBs damaging [5], using heating devices, de – soldering systems and cutting machines, to cut the baseboard in small parts, new approaches for dismantling are only developed to extract the electronic components from PCBs without any damage on the PCB, [6]. Disassembly and dismantling procedures can be executed in many ways. In [7], a brief description regarding different aspects of sustainability and efficiency of PCBs recycling is accomplished. It is mentioned that there are three types of dismantling processes for PCBs: manual, semi – automatic and automatic. The manual dismantling is common in developing

countries, while automatic dismantling are the most expensive, [8]. This is why many researches and approaches opt for semi – automatic dismantling, because they are effective, cheaper than automatic ones and more flexible [7]. While many semi-automatic approaches use de-soldering systems, heating devices or rough rotating brushes for electronic components removal, followed by the usage of some external forces to completely remove the component from the PCB (vibration, external forces, shearing and impact). Vibrations, shearing or other external forces may have a negative impact on the baseboard, so that the leaching process for precious metals recovery might become less effective. Heating devices may have an unwilling impact on the baseboard where precious metals are located.

In this paper, a different approach to dismantle capacitors is presented. Starting from an initial concept previously publishes in [9], we give details on the design of a semi-automated architecture, where a manipulator robot equipped with a rotary tool and an artificial vision system makes the capacitors removing process flexible and accurate. The paper discusses both simulation performance evaluation and preliminary results of the physical system. In addition, multiple challenges that emerged during physical system implementation are presented together with the adopted solutions. Next, functionality goals and robot cell description are discussed. In the end conclusions regarding the

2. Functionality goals

The main goal of the proposed system consists in its usage in electrolytic cylindrical capacitors and solid dielectric capacitors dismantling from PCBs. The present study for the design of this robotic cell revealed that E – ATX, ATX, Micro ATX and mini ATX boards are the most used types for computers. The necessary equipment for this robotic cell 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 artificial vision system for image 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, with an extraction tool with saw teeth type and a sensor responsible for tool’s triggering for the drill’s rotation;
- a centralized coordinating process system, responsible with algorithms run for components and components coordinates detection for dismantling, data transmission and communication with the robot’s controller;
- components storage box.

The functionality of the entire system is presented in figure 1.

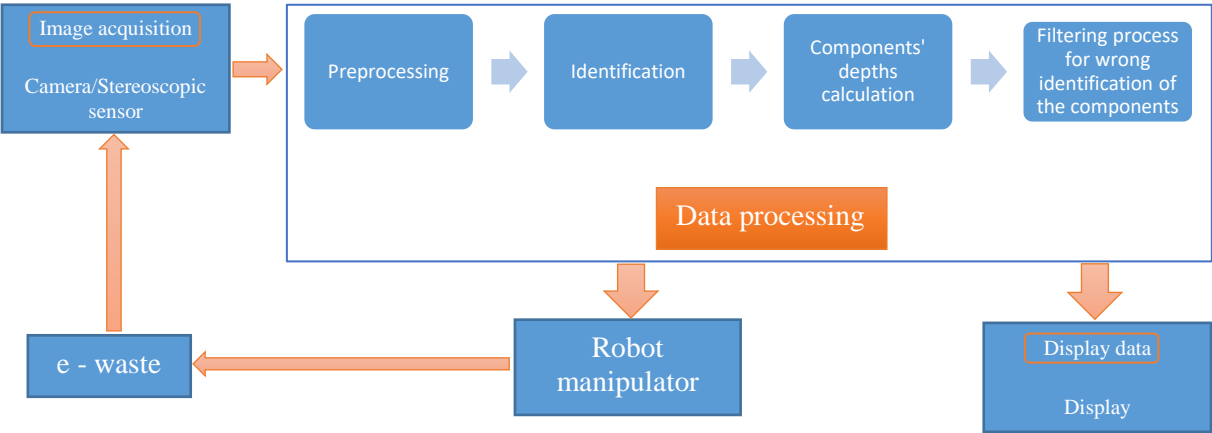


Figure 1. Diagram of the system’s functionality

3. Dismantling architecture design and implementation

3.1. Robot manipulator and virtual simulations

Taking into account the necessary mechanical movements necessary to dismantle component from PCBs, an industrial IRB 140 manipulator was chosen. Before physical testing, a consistent number of simulations have been accomplished so that an optimized kinematics was adopted using a specific industrial robots simulation software – Robot Studio. A 6 – axes industrial robot, with a pay load of 6 kg, a 0.81 reach and a 0.1 mm accuracy was considered as being the best for this procedure (figure 2).

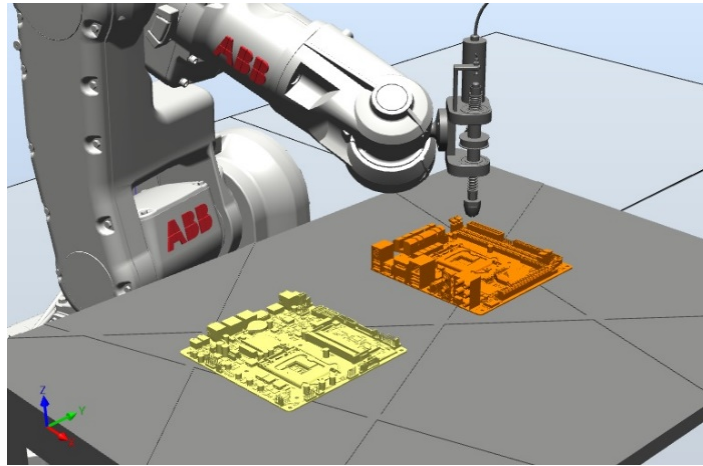


Figure 2. Virtual simulations for optimized kinematics using Robot Studio

3.2. Artificial vision system

The artificial vision system is based on a Zed stereoscopic camera that provides both the necessary resolution and information related to the depths of the objects situated in the workspace. The Hough transform was used for capacitors positions identification. In figure 3, an example of the artificial system output is illustrated, where the correct interest positions marked with blue margins and false positions marked with red. The preliminary results showed that there is the possibility for false positive identification, thus another step was employed to solve this problem. This additional step is based on the information related to the depths of the components, which allows the definition of a threshold value that can be used to validate a location as a component to be removed from the PCB. After multiple tests using a Matlab implementation of the algorithm, the results showed an accuracy of 86%.

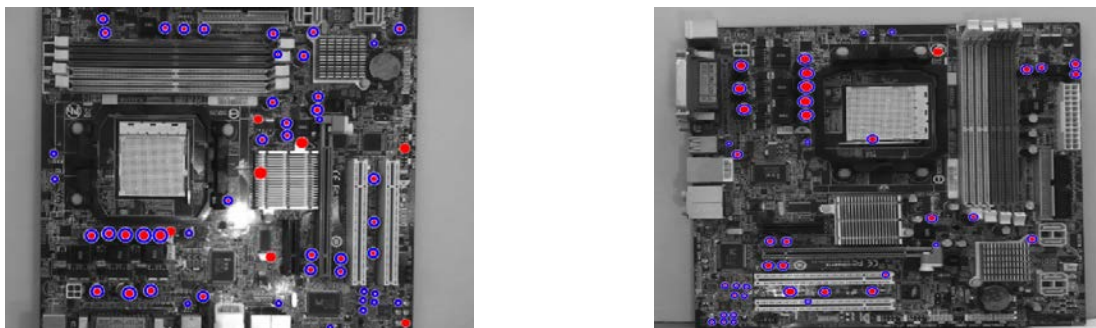


Figure 3. Capacitors identification algorithm results using the proposed integrated system for image processing

3.3. Custom tool design

A mandrel type tool with saw teeth has been designed for capacitors dismantling. The necessary mechanical movements for each capacitor's perforation was accomplished by the robot manipulator. The geometry of the tool permits the perforation of each capacitor of the PCB. When the perforation process is accomplished, the tool is not rotating. After the successful perforation of each capacitor, a sensor triggers the mandrel type tool so that the head starts its rotations. The perforation process ends when the friction force is big enough so that the tool's rotations can successfully accomplish the dismantling procedure. The geometry of this tool is presented in figure 4.



Figure 4. A CAD design and a real mandrel type tool with saw teeth for capacitors dismantling

The artificial vision system identifies the capacitors to be dismantled. The robotic arm reaches the capacitors' heads, when the perforation process begins. The control over the pushing force is obtained through the adjustment of the proximity sensor's positioning. When the perforation process is accomplished, without the rotation of the tool's head, a proximity sensor is activated so that the robotic arm stops its feeding move. When the sensor's triggering action begins, responsible for the head rotation, a number of rotations is performed. After a pre-set number of rotations, the electric screwdriver is stopped and the robotic arm executes a retirement movement from the workspace. Once the capacitor was successfully dismantled, the robotic arm returns to a calibration position with respect to the fixed dashboard's coordinate system and the identification procedure of another capacitor is initiated. The assembly of the screwdriver responsible for capacitors' extraction is illustrated in figure 5.



Figure 5. A 3D CAD model and the original model tool for capacitors' dismantling
1 – mandrel; 2 – mandrel sliding spindle; 3 – clamping spring; 4 – device support; 5 – bearings; 6 – gears assembly with belt connection; 7 – rotation shaft; 8 – supporting mobile spring in the workspace with limited backlashes values; 9 – proximity capacitive sensor with a continuous adjustment possibility; 10 – a programmable screwdriver

3.4. Robotic dismantling system

A centralized process coordination system for components detection algorithms run and components extraction, positions detection, communication with the robot's controller and data transmission was used. The number of rotations of the tool after the perforation of each capacitor has been established using this system. Of course, after a consistent number of simulations, the optimum number of rotations for capacitors dismantling has been chosen accordingly. 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. Of course, the procedure capacitors are attached to the PCB is also studied, as long as the heights and widths of the connection pins represent important characteristics to be considered in the design of the cell. In addition, the positions of each capacitors, their placement on the PCB and the fact that other electronic components may be situated in the neighbourhood of each capacitor are important factors that were taken into account for successful dismantling procedure of the presented robotic cell.

The heights of the connection pins have an influence on each capacitor's position on the PCB. It was observed that the capacitors with smaller pins have a straight position, without inclination, while the capacitors with longer pins may have their positions affected, as they can easier slant. This fact, of course, could seriously affect the dismantling procedure, as long as the dismantling tool is situated right above the PCB, so a vertical position of the capacitor is needed. If the slant of a certain capacitor is big enough so that the image processing system did not identify the head of the capacitor, then the dismantling procedure will not function properly. A similar case study for a certain PCB is presented in figure 6.



Figure 6. Different attachment ways for capacitors to the PCB
1,3 – longer pins and 2, 4 – smaller pins

The originally developed image processing system works with different shape filters, so the full view (or approximately full view) of the capacitors' heads is needed. Many similar details have been taken into consideration for the design of the present cell. Among these, the most important detail consists in a classification of the capacitors, depending on their heights and diameters' sizes. Thus, the capacitors' classification depending on their heights and the diameters' dimensions is as follows:

- Class 1: $D = 10$ mm and $H = 25$ mm;
- Class 2: $D = 8$ mm and $H = 18$ mm;
- Class 3: $D = 8$ mm and $H = 15$ mm;
- Class 4: $D = 8$ mm and $H = 12$ mm;
- Class 5: $D = 5.2$ mm and $H = 8$ mm;
- Class 6: $D = 4.2$ mm and $H = 8$ mm.

Of course, the dimensions from each class may have small variations regarding their dimensions. The entire robotic cell during a dismantling procedure test is presented in figure 7.

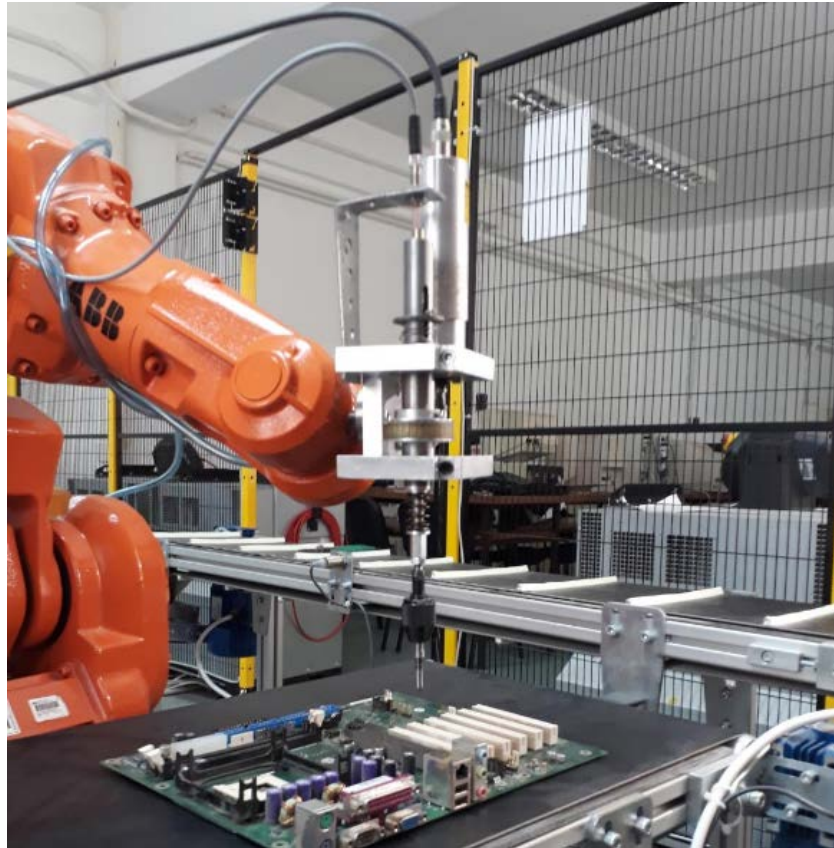


Figure 7. Robotic cell assembly

4. Conclusions

This work is set to design and implement a semi-automatic robotic cell for capacitors dismantling from PCBs. The architecture includes: a 6 degrees of freedom manipulator robot, a custom designed rotary tool with a screwdriver and a saw type teeth mandrel tool, an artificial vision system and a centralized computational system. Regarding system capabilities a number of six classes of capacitors were defined, depending on their sizes and depths.

During extraction tests, it was emphasized that there are necessary less than 3 complete rotations of the mandrel type tool (extraction tool), with a medium angular velocity of 60 rotations/minute. The usage of a rotary tool for dismantling, unlike other procedures that use external forces and vibrations, is a good thing, because the PCB is not affected and the further leaching procedures can be accomplished in better conditions, as long as the latest researches on dismantling procedures are focused on minimum damage of the PCB.

The success rate at the end of the extraction process was 75%. The originally designed extraction tool worked very well for capacitors belonging to classes 1, 2, 3 and 4. For capacitors belonging to classes 5 and 6, any deviation with respect to the center of the capacitor's diameter may cause dysfunctionalities of the extraction tool, due to the existence of some small backlashes and the insufficient rigidity of the tool's support. Thus, the diameter's dimension is an important situation to be taken into account and further investigations will be considered.

After the investigation of the extracted capacitors, it was emphasized that for capacitors with diameters that are larger than 6 mm, a plastic deformation of the capacitor occurs. For capacitors

belonging to class 1, the tool's perforation depth was 1.2 mm. For capacitors belonging to classes 2, 3 and 4, the tool's perforation depth was the same as the tool's teeth heights. For capacitors belonging to classes 5 and 6, the tool's perforation depth was 0.2 mm and the liquid dielectric from the capacitors belonging to these classes was not released.

Future work will include optimizations for both the artificial vision system and the extraction procedure. The goal will be to increase the reliability of the physical system and to reduce the time needed for a full dismantling of a PCB.

Acknowledgement: This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCDI-UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0562/TORA, within PNCDI III

5. References

- [1] Gunningham N, 2009 Environmental law, regulation and governance: shifting architectures, *Journal of Environmental law* **21** pp 179 – 212
- [2] Zhang W, Ren J, Liu S and Yuan Z, 2016 Mechanism and clean procedure to extract gold from printed circuit board, *Procedia Environmental Sciences* **31** pp 171 – 177
- [3] Abdelbasir S M, El – Sheltway C T and Abdo D M, 2018 Green processes for electronic waste recycling: a review, *Journal of Sustainable Metallurgy*.
- [4] Hanafi J, Jobiliong E, Christiani A, Soenarta D C, Kurniawan J and Irawan J, 2012, Material recovery and characterization of PCB from electronic waste, *Procedia – Social and Behavioural Sciences* **57** pp. 331 – 338 .
- [5] Park S, Kim S, Han Y and Park J, 2015, Apparatus for electronic component disassembly from printed circuit board assembly in e-wastes, *International Journal of Mineral Processing* **144** pp. 11-15
- [6] Lee J, Kim Y and Lee J, 2012, Disassembly and physical separation of electric/electronic components layered in printed circuit boards (PCB), *Journal of Hazardous Materials* **241 – 242** pp. 387 – 394
- [7] Zeng X, Zheng L, Xie H, Lu B, Xia K, Chao K, Li W, Yang J, Lin S and Li J, 2012, Current status and future perspective of waste printed circuit boards recycling, *Procedia Environmental Sciences* **16** pp. 590 – 597
- [8] Kaya M, 2016, State of the art in printed circuit board (PCB) recycling technology, *The 15th International Mineral Processing Symposium (IMPS)*
- [9] Stamate C, Doroftei I, Chirita D and Burlacu A, 2019, On designing an automated tool for capacitors removal from waste printed circuits boards, *IOP Conf. Series: Materials Science and Engineering* **591** pp 1-8.