Eye-to-Hand Architecture for PCB Automated Dismantling Procedures

Ioan Doroftei
Dept. of Mechanical Engineering, Mechatronics and Robotics
"Gheorghe Asachi" Technical University of Iasi
Iasi, Romania

Adrian Burlacu*
Dept. of Automatic Control and Applied Informatics
"Gheorghe Asachi" Technical University of Iasi
Iasi, Romania

***Abstract*—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. 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. The paper details the implementation layout and highlights the advantages of the proposed architecture.**

***Index Terms*—robotic system, eye-to-hand, PCB dismantling, electronic waste**

I. 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 [1], [2].

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 [3]. In [4], it is presented a newly-designed and automatic EC disassembling apparatus, that includes an IR heater and steel brushes. All the experiments in [4] were accomplished using laptops PCBs. This device proved to be ineffective for screws and high energy consumer.

The main goal in [5] 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.

Currently in Romania the proposed reduction of waste resulted from PCBs are in a research phase, with no technological routine that can be replicated. In the context of TRADE-IT research project, we propose a eye-to-hand architecture based on a robotic system equipped with a custom tool to dismantle capacitors. In comparison with state of the art, the proposed system will mechanically dismantle the capacitors while protecting the other remaining electronic waste. The paper presents the architecture design in section II, while the implementation details are revealed in section III. The dismantling scheme experimental results are presented in section IV, while the conclusions are drawn in section V.

II. Architecture 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.

Different problems can be avoided by applying mechanical dismantling [5]:

- 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;

∗corresponding author: aburlacu@ac.tuiasi.ro
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

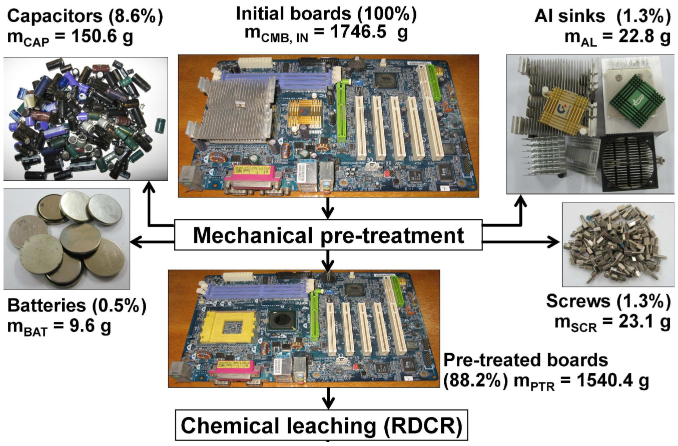

Fig. 1. Flowchart of the semi-automated dismantling process [6]

- 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;

The preliminary analysis on WPCB revealed 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 [7].

The necessary equipment for the 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 proposed 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 process coordination system for components detection algorithms run and components extraction, positions detection, communication with the robot's controller and data transmission was used.

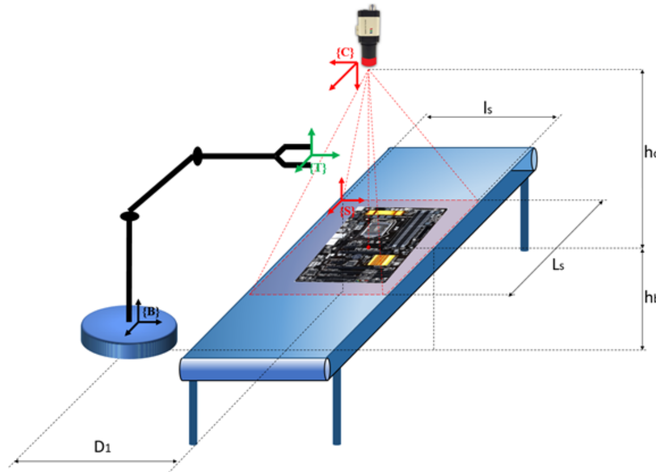

Fig. 2. Architecture design

Currently the focus is on dismantling cylindrical capacitors and solid dielectric capacitors, however the architecture can be easily customized for other components. Next we detail each component used in implementation.

III. Architecture implementation

A. 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. This industrial robot is a six axis multipurpose robot that handles payload of 6 kg, with long reach (810 mm).

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.

Fig. 3. Robotic system

Fig. 4. RGB-D sensor

B. 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 RGB-D sensor 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 [8]. 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.

To ensure high quality RGB-D acquisition, a custom light source was built. This allows for uniform distribution of light in the acquisition process.

C. Custom tool

Once the positions of the capacitors are identified in the image, the dismantling procedure can be employed. The robotic arm should operate for each capacitor under specific values of height and pressure. A custom 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).

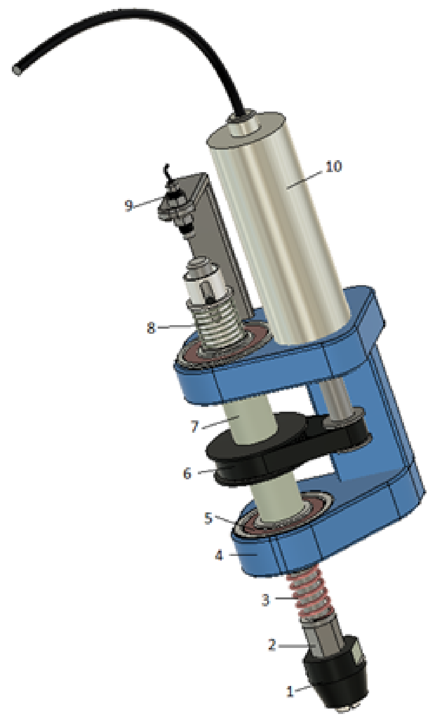

Fig. 5. Custom tool for dismantling capacitors: 1-Chuck; 2-Sliding axle with chuck; 3-Fastening spring; 4-Device support; 5- Bearings; 6- Toothed wheel assembly connected with strap; 7- The axis of rotation; 8- Spring to hold the spindle in the work area; 9- Capacitive proximity sensor with possibility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

This device must be moved in the working area by the robotic arm in the motion coordinates on the three X, Y and Z axes. To extract the capacitors from the motherboard, 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 this tool is that it does not require very high precision for positioning on the Z axis.

This device just needs to be positioned above the center of the extraction condenser and lowered until the spindle reaches the aluminum surface. While the robotic arm will advance on the z axis, this device will slide back as a result of the action of tensed arcs that will resist mechanical resistance. 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.

D. Capacitor dismantling algorithm

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 capacitors position. Image adjustment and edge detection is performed. The circular Hough transform is used to compute the most probable capacitors position in the image.
- 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.

IV. Experimental results

Before putting it into practice, part of the proposed architecture was simulated. More precisely, the simulation revealed the behavior of 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.

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.

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 dismantle 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.

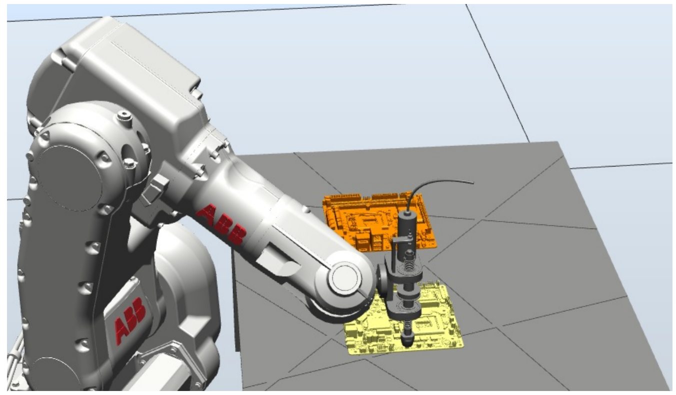

Fig. 6. Workstation simulation in Robot Studio

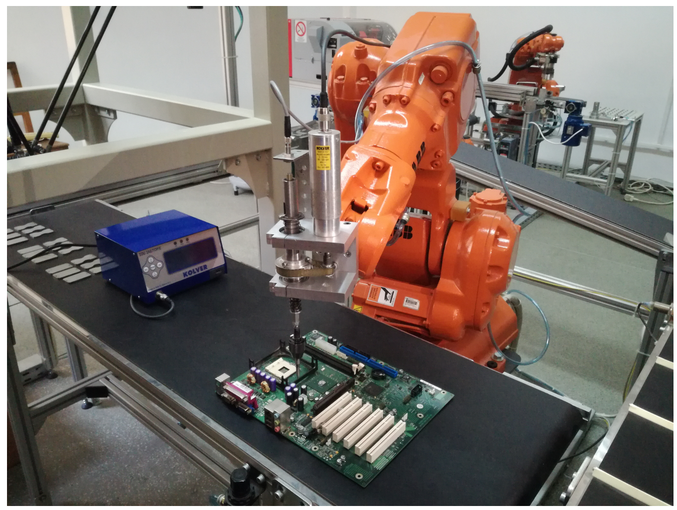

Fig. 7. Custom tool attached to robotic system

During the experiments performed with the final tool design, 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.

The artificial vision systems is used to detect the 3D position of the capacitors. In the current configuration the implemented algorithm has a success rate of over 85%. This outcome is influenced by the PCB layout, in figure 8 a detection result is illustrated, the red dots being the false positives.

An improvement could be the use of an artificial neural network classification. An detection scheme such as You Only

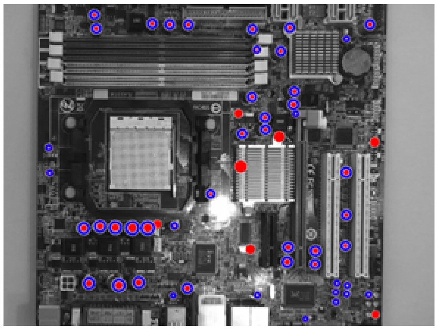

Fig. 8. Capacitors identification

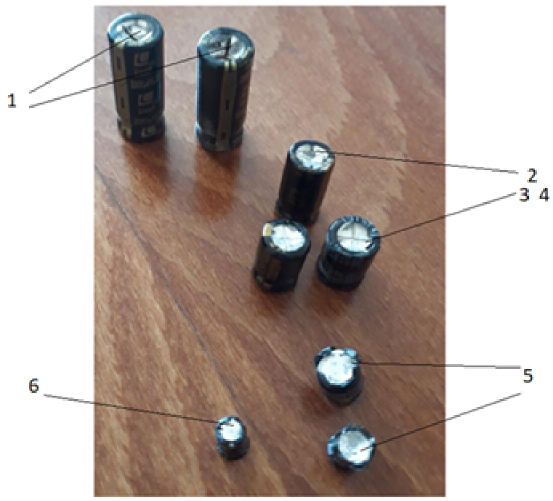

Fig. 9. Classes of capacitors removed by the custom tool

Look Once (YOLO) or Aggregate Channel Feature (ACF) are under investigation. Currently we are working on enlarging the training database with different types of PCB.

Regarding efficiency, the current tool can be used to dismantle six classes of capacitors (fig.9).

V. 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 from a RGB-D sensor to guide a custom tool. A custom tool is attached to the last link of a six degrees of freedom manipulator robot. The dismantling system was first simulated and than implemented. The experimental results showed good results for six classes of capacitors.

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.

References

[1] V. Pérez-Belis, M. Bovea and V. Ibáñez-Forés “An in-depth literature review of the waste electrical and electronic equipment context: trends and evolution”, Waste Manag Res, Vol. 33, pp. 3-29, 2015

[2] X. Zeng and J. Li, “Measuring the recyclability of e-waste: an innovative method and its implications”, J Clean Prod, vol. 131, pp. 156-162, 2016

[3] C. Achillas, D. Aidonis and C. Vlachokostas, “Depth of manual dismantling analysis: a cost–benefit approach. Waste Management”, Vol. 33, pp. 948–956, 2013.

[4] S. Park, S. Kim, Y. Han, J. Park, ”Apparatus for electronic component disassembly from printed circuit board assembly in e-wastes”, International Journal of Mineral Processing, vol. 144, pp.11-15,2015

[5] B Kopacek, P Kopacek, ”Extracting rare materials from electronic scrap”, IFAC Conference paper archive 48-24, pp 157-161, 2015

[6] S-A Dorneanu, “Electrochemical recycling of waste printed circuit boards in bromide media. Part I: preliminary leaching and dismantling tests”, Studia Universitatis Babes-Bolyai, Chemia, vol.62, no 3, pp.177-186, 2017.

[7] C. Stamate, I. Doroftei, D. Chirita and A. Burlacu, ”On designing an automated tool for capacitors removal from waste printed circuits boards”, IOP Conf. Series: Materials Science and Engineering, vol.591, pp 1-8, 2019.

[8] L. Ortiz, E. Cabrera, L. Goncalves, Depth Data Error Modeling of the ZED 3D Vision Sensor from Stereolabs, Electronic Letters on Computer Vision and Image Analysis, vol. 17(1), pp. 1-15, 2018.