Sorting System for e-Waste Recycling using Contour Vision Sensors

Rapolti Laszlo, Rodica Holonec, Romul Copîndean and Florin Dragan
Department of Electrotechnics and Measurements
Technical University of Cluj-Napoca
Cluj-Napoca, Romania
laszlo.rapolti@ethm.utcluj.ro

***Abstract*— Recycling old electronic components facilitates the recovery of valuable materials that can be used to produce new ones. As a result, energy is saved, pollution and greenhouse gas emissions are reduced, and many natural resources are salvaged by extracting fewer raw materials. The paper focuses on rapid sorting method developed for separating the dismembered components of a personal computers motherboard. After a simultaneous disassembly process of the board, some of the components like plastics, silicon chips, surface-mount devices and magnetic components need to be intelligently sorted, therefore economically separated. In the sorting process a conveyor belt was used to transport the components one by one. A contour vision sensor was used to acquire and process the images, consequently to recognize the components. The visual sensor binary code output is connected to a Mitsubishi FX3G programmable logic controller. Finally, electro pneumatic valves with directional air flow control are used to position the objects from the conveyor belt into separate bins.**

Keywords—e-waste, recycling, sorting system, vision sensor, machine vision, programmable logic controller

I. INTRODUCTION

Electronic waste (e-waste) is a main concern for humanity for it affects nearly every system in the human body because they contain a variety of toxic components which can include mercury, lead, cadmium, barium and lithium. Even the plastic casings of electronics products contain polyvinyl chloride (PVC). The health effects of these toxins on humans can be damaging. The e-waste amount is growing in many countries, due to the increased number of electronics manufacturing. By recycling these materials humanity can have a lot of renewable materials, for example hydrogen gas was created by a gasification process of the waste components. [1-2].

The separation of electronic waste, particularly of IT and communication equipment scraps has become a complex process over the last few years, because optimal recycling depends precisely on how sorting is performed. Engineers and researchers from industry and academia proposed and developed different intelligent automated systems for dismantling, segregation and recycling e-waste [3-6]. A complex sorting system (Fig. 1) for dismembered e-waste components can use on the conveyor belt different types of sensors and actuators.

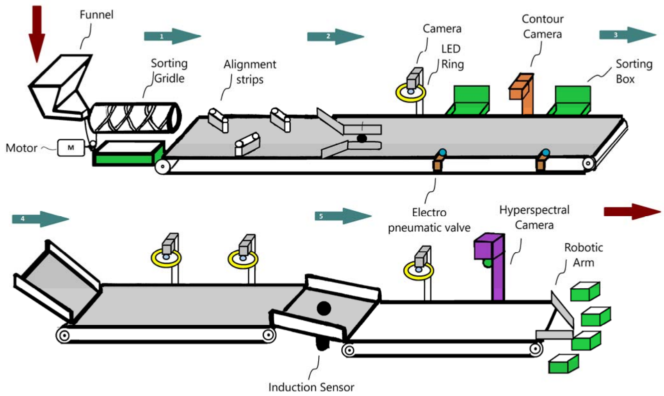

Fig. 1 Complex sorting system for dismembered e-waste components

Thus, in such sorting systems, the different sensory elements could be present: cameras, vision, color or hyper-spectral sensors, optical barriers, inductive proximity sensors, X-ray fluorescence detectors. The actuators used to control the motion in the sorting systems can be of the following type: pneumatic, electric, thermal, magnetic or mechanical. The configuration of these systems is evolving continuously to new digital technologies like machine vision, machine learning, artificial intelligence, augmented reality and energy efficient robotics. [7].

The traditional machine vision systems for automated sorting processes need separate hardware and software running on Personal Computers (PCs) or/and other embedded systems like Programmable Logic Controllers (PLCs) [8-9]. The newer industrial vision systems use vision sensors or smart cameras (Fig. 2) where the lighting, lens, camera and the controller are combined in a single unit [10-11]. In this way the inspection operation is simple and robust. The difference between them is that the smart camera can combine different inspection possibilities while the vision sensors are specialized for just one type of application like contour detection, color inspection or bar code reading. For example, the O2V contour vision sensor from IFM is ideal for applications where the objects vary in shape, size or shade while O2D vision contour sensor from IFM is ideal in applications where the object's shape is repeatable and defined.

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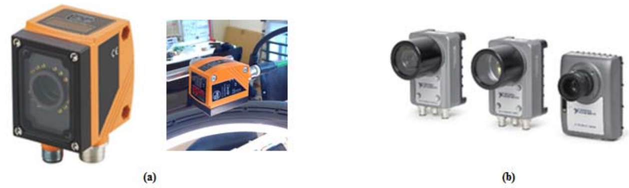

Fig. 2 (a) Vision sensor (O2V100-IFM), (b) Smart Cameras (National Instruments)

II. SYSTEM DESCRIPTION

The system built for sorting the E-waste components (Fig. 3) from PC motherboard was realized (Fig. 4) using the following components: the conveyor belt, an AC induction motor controlled by a variable frequency drive (VFD), a contour vision sensor (IFM O2D220), a LED lighting ring with variable color temperature and light intensity, four electro valves with directional air flow control used to position the objects from the conveyor belt into separate bins. The electro valves are controlled by a PLC (Mitsubishi FX3G).

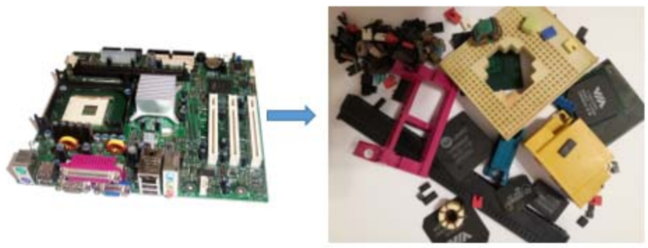

Fig. 3. The components resulted from the dismembered PC motherboard

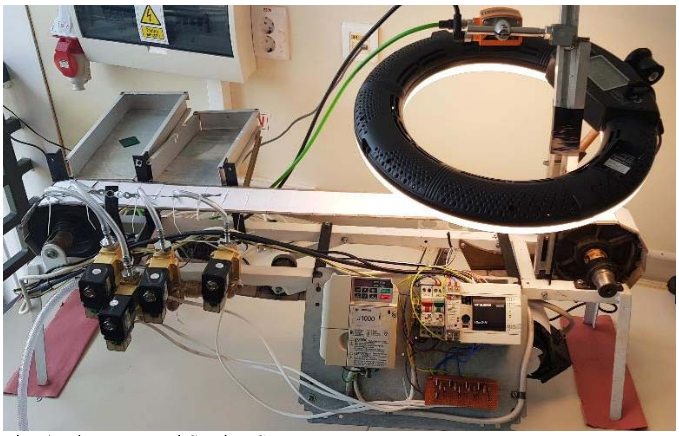

Fig. 4. The Proposed Sorting System

III. THE SORTING PROCESS

The sorting process (Fig. 5) starts by placing the components one by one on the conveyor belt. As a component moves on the conveyor belt, the vision sensor will detect it and in about 1.2 seconds it will be recognized. All data about the components are stored in the nonvolatile memory of the sensor in a form of a binary code. When the components are recognized the vision sensor will activate the appropriate outputs at low or high level according to the binary code These outputs are connected to the digital inputs of a Mitsubishi Electronics PLC that will finally activate one of the four electro pneumatic valves in order to remove the objects from the conveyor belt into the appropriate sorting bin.

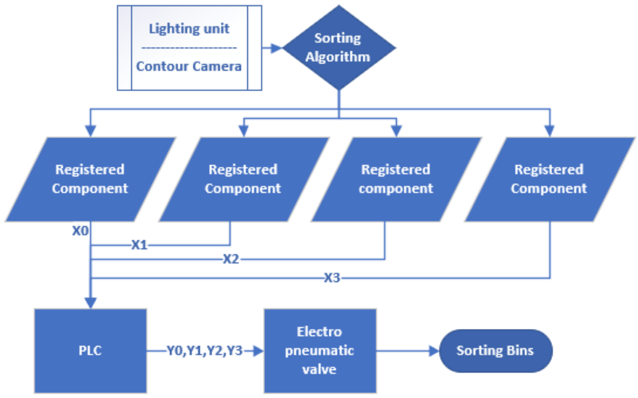

Fig. 5. The Flow chart of the sorting process

A. Camera Algorithm

The vision sensor uses a contour detecting algorithm to detect the edges of the components. Its focus must be manually set for the algorithm to work correctly and the distance between the object analyzed and the vision sensor must be set in such a manner that the component occupies at least 5% of the sensors view. The contour tracing algorithm was evaluated according to the processing time, the accuracy of contour tracing, data size of the files with the traced contour and the ability of the program to accurately reconstruct and enlarge the saved contour from the saved data. The IFM model O2D220 vision sensor uses incident light or backlight to detect the image of an object and compares it with the defined contours of one of the several models in the reference database (Fig. 6) Depending on the degree of conformity, orientation and tolerance, the object is classified as “pass” or “fail”.

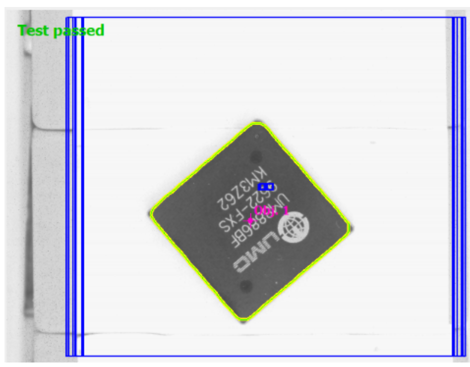

Fig. 6 Components contour detection and classification

The backlight detection algorithm works as follows, if the luminance difference between the main object (foreground) and the background is high, backlight images are produced. The object in front of the sensor will reflect light back to the vision sensor and so the sensor can make a difference between the object and background. After processing the images, the user can refine the detected edges and help the software to recognize the object with a much higher accuracy. This data about the object and its contour are stored in the memory of the vision sensor. The sensor has the option to use infrared light (880 nm) or an external source depending on the conditions and the desired image quality.

The proposed system uses an external light source (LED ring) which was placed around the camera and set to a color temperature of 3200K and a light intensity of 77%, this way the image was well balanced, and overexposures didn't appear.

A. The PLC Controlling System

The Mitsubishi Electronics PLC was programmed in order to control by its outputs Y1 to Y4 the electro pneumatic valves (Fig. 7) In the first sequence with the [MOV K1X0 D0] instruction all the inputs are stored in the register named D1. In this way data sent from the output of the vision sensor will be transferred to the register D1. The following instruction line [=D1 K1] compares the values from the register D1 with a constant value "1" which will transmit impulses to a counter named C1. If the counter C1 value is 1, meaning only one object is on the conveyor belt a specific code sequence will be executed. In case C1's values are greater than 1, more than one object is on the conveyor belt and more information must be processed. Thus another leader diagram sequence was created.

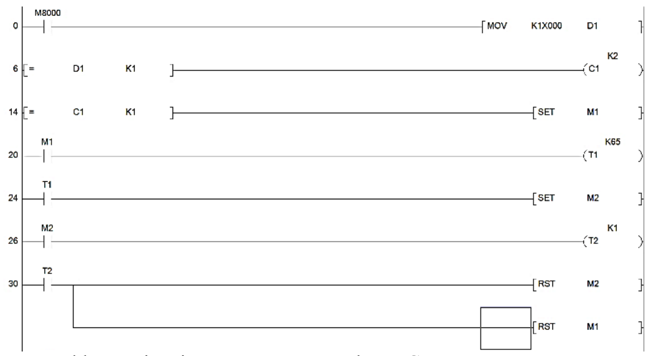

Fig. 7. Ladder Logic Diagram Program on the PLC

In order to control the electro pneumatic valves with a voltage source of 24V, a MOSFET transistor was used (Fig. 8). The gate of the MOSFET was connected to the PLC output lines. When the output becomes HIGH the current can pass through the MOSFET, therefore activating the electro pneumatic valve. A diode was placed in parallel as a flywheel diode in order to protect the MOSFET from any self-generated back-electromotive force.

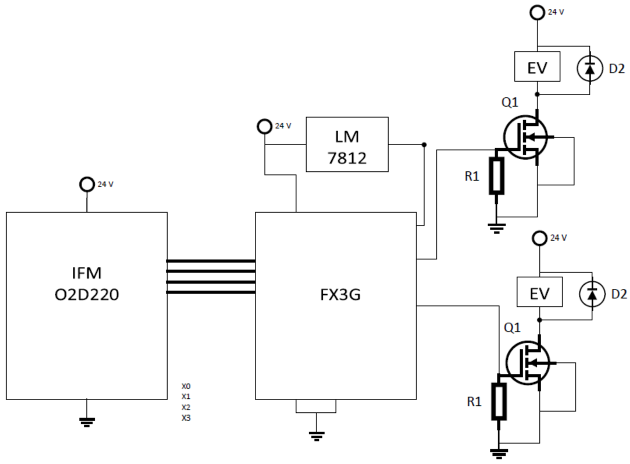

Fig. 8 Circuit diagram of the system

IV. EXPERIMENTAL DATA

The experiments started out with different types of components from a dismembered motherboard of an old PC. First all the components where placed on a white background and observed through the vision sensor, by doing so the best visible components where picked to be tested. Images were processed using different types of illuminations. The best results where yielded with a warm white color at 3200 K and a light intensity of 77 %. Ain this conditions, all the components images where registered in the memory of the vision sensor. The vision sensor was programmed with the optimal parameters (focus, edge detection, detection zone) and then all the components placed under it were verified against the sensor database (Fig. 9). After this checking, the components where placed one by one on the running conveyor belt and all the outputs of the vision sensor where registered on the PLC.

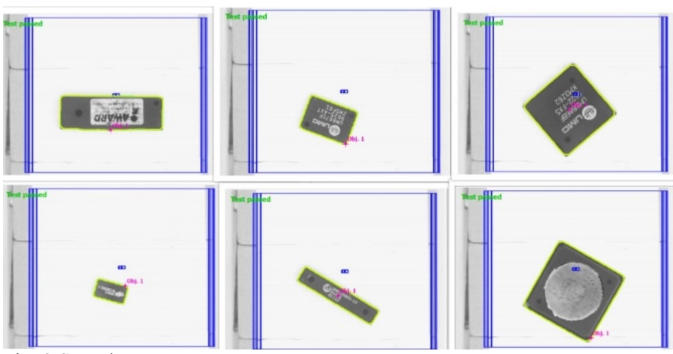
Fig. 9 Sorted components

The setting of the conveyor belt speed was made in such a manner that the vision sensor to have time to process images and components to arrive in time in front of the electro pneumatic valves. In order to know the vision sensor recognition accuracy (Table I) all the components where scanned 10 times.

TABLE I. VISION SENSOR RECOGNITION ACCURACY

Test	CPU	CHIP 1	CHIP 2	CHIP 3
Test 1	99%	97%	100%	99.99%
Test 2	100%	89.99%	77%	99.80%
Test 3	89%	98.80%	98%	89.70%
Test 4	80%	98%	100%	90%
Test 5	78%	99.99%	99.90%	81%
Test 6	99%	99.89%	89%	94%
Test 7	87%	100%	99%	99%
Test 8	84%	80%	100%	99%
Test 9	100%	88.70%	86%	98%
Test 10	99.99%	97.99%	95%	99%
Pass	**90%**	**100%**	**90%**	**100%**
Fail	**10%**	**0%**	**10%**	**0%**

Every time the components where tested each of them was rotated in another position or different illumination conditions were given. When an unknown component was placed under the camera it didn't recognize it at all. The match conditions were set to be a minimum of 80% of the stored model. For each scanned component the vision sensor software gave a feedback to the user with the match percentage, evaluation time, orientation, position of the component and the component name (Fig. 10).

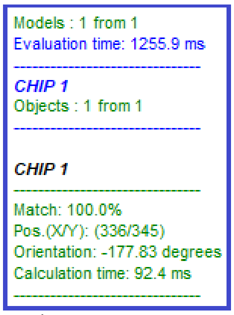

Fig. 10 Details of an evaluated component

The time it takes a component to get in front of an electro pneumatic valve was calculated based on the distance between the camera and the valves and the speed of the conveyor belt. After some minor calculations and adjustments in the programing of the PLC the band was fully functional and was able to separate all the components.

II. CONCLUSIONS

Electronic waste sorting is possible with some effort from humanity. This paper proposed and designs a system capable to segregate some components coming from a dismembered PC Motherboards. By using a single contour vision sensor, a conveyor belt, a PLC and four electro pneumatic valves, the on-line separation of different types of components in different sorting bins was possible. With a more complex conveyor belt and a more complex system of sensors and cameras it could be able to sort many other types of components. For example, with the help of a hyperspectral camera it would be able to separate the same components which contain different types of materials in them.

III. ACKNOWLEDGMENTS

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