The PLC Implementation of an Automated Sorting System using Optical Sensors

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Abstract *– WEEE (Waste Electrical and Electronic Equipment) Directive 2012/19 / EU refers to the appropriate recycling of electrical and electronic equipment waste. The objectives of this directive are to preserve, protect and improve the quality of the environment, protect human health and use natural resources in a prudent and rational manner. In this context, the intelligent separation / sorting of waste has a principal role. Thus, the integrated circuit board waste can be separated using sorting systems based on both specific sensing elements and computerized visual inspection. Optical sorting is the automated process of sorting solid products using cameras and / or optical sensors. By using their principles and proper software, objects can be sorted by their color, size, shape, structural properties and chemical composition. In this paper is presented an automatic sorting system on the conveyor belt, according to the size and color of the components from a dismantled PC motherboard. The application was made with a FX1S-14MR PLC from Mitsubishi Electric, and was based on the use of infrared optical barriers and color sensors. For the storage of the sorted components in the container, electro-valves using air under pressure were used.*

Keywords – *electronic waste, sorting system, PLC, optical sensors*

1. INTRODUCTION

In the perspective of recycling electronic waste, the process of separation or sorting is a very important one. There are numerous methods of sorting but those based on dismantling have the advantage of insulating dangerous components (polyvinyl chloride, mercury). In PCB recycling systems two principles are used: the selective sorting based on “inspection and sorting” stages and simultaneous sorting based on “evacuation and sorting” stages [1] [2]. Regarding the second method, PCB components can be sorted using intelligent systems based on specific sensors and visual computerized inspection means [3]. The purpose of intelligent sorting is to keep the shape and structure of PCB components without crushing them, in order to separate and easily, economically recycle the secondary waste. The application of the proposed technologies would lead to a high rate of recovering different materials like gold, silver, copper, aluminum, tin, platinum, palladium, gallium, tantalum, tellurium, germanium, selenium, and iron.

Generally, an optical sorting system on a conveyor belt has four main components: the system feeding with objects to be sorted, the optical sensors system, the software for processing the acquired signals and the separation system itself [4]. The objective of the feeding system is to ensure the presence of the objects on the conveyor belt evenly, with no clogging, on a constant speed. Optical system includes the lighting system and the sensors placed in the flux of the inspected objects. The system for processing the acquired signals compares the objects with the accepted/rejected thresholds defined by the user for the objects classification and the separation control system. The separating system usually is based on compressed air electro-valves, especially for small size objects, and on mechanical devices (palaces, rotating gutters). An ideal sorting system depends on the characteristics of the objects and user’s objectives, facts that imply the choosing of the proper sensors, hardware and software as well as the mechanical platform.

In the optical automated sorting systems different types of sensors and execution elements are used. As sensorial elements there are to be noticed:

- Cameras
- Optical sensors: optical barriers, color sensors,
- Spectral sensors
- X rays technologies. These are used to detect different types of materials depending on their density

The actuators used in the sorting systems can include different type of movers:

- Pneumatic (compressed air nozzles)
- Electric: engines, servomotors, (separation palettes, gutters)
- Mechatronic (robot arms)

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Optical sorting systems use different categorization criteria based on the visual characteristics of the objects: shape, size, color, texture, etc. [3][5][17]. As the number of those criteria entering in a sorting algorithm is higher, the success of separating the objects is warranted.

In the implementation of a sorting system the automation must be done in terms of "low cost, "low maintenance", "reliability" and "simplicity". Our paper proposes a PLC (Programmable Logic Controller) based system where the optical sensors are meant to quantify two sorting features: object size and color.

Different sorting systems based on the objects height variation were implemented [6]. Most of them use photo-electric sensors. An optical barrier is formed by a light emitter whose beam is focalized on an optical sensor. Infrared lasers or Infrared LEDs of specific wavelength may be used in order to emit light. The most used optical sensors are photo-transistors, photo-diodes and photo-resistances. An object entering in the area of operation of the light beam interrupts the sensing path between the emitter and receiver. In figure 1, one may notice the placement of two optical barriers X1, X2, in order to detect objects of different heights.

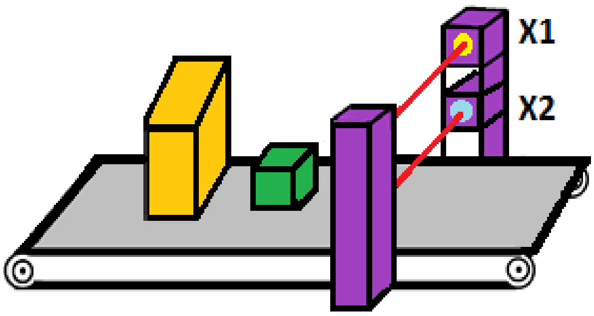

Fig 1: Optical barrier with two beams

Regarding the sorting process based on object color feature, unlike a video camera which needs complex equipment for processing data, a color sensor could be the proper solution in prototyping an automated sorting machine [7], [8]. For instance, the output of the TCS230 Color Sensor is a square wave with the frequency being directly proportional to light intensity (irradiance). The sensor detects various colors and it is based on an array (8x8) of photodiodes that have three different color filters. The processing of the sensor output signal is relatively simple because the measurement of frequency is needed and this can be easily done using micro-controllers, PLCs or data acquisition boards.

2. SORTING BY OBJECT SIZE

The experimental stand from the figure 2 was designed for sorting electronic components by their size and it was implemented on a conveyer belt where were installed both the sensors and the actuators.

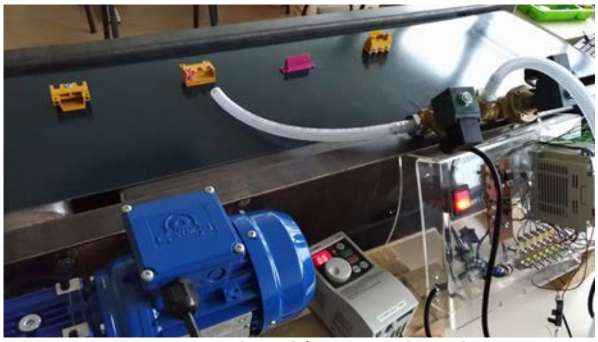
Fig. 2 Experimental stand for sorting objects by size

The electric scheme of the sorting system for objects with different sizes is presented in figure 3. In order to implement the application, a PLC of FX3G type [9] was used.

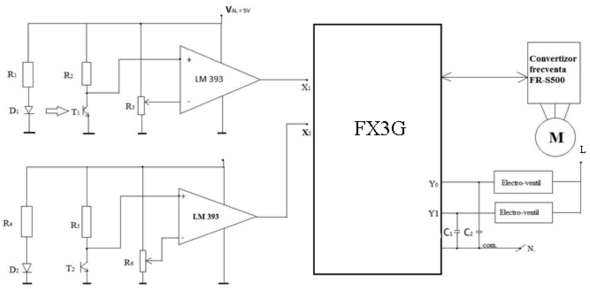

Fig. 3 Electric scheme of sorting system based on object size

Two optical barriers in infrared were used. They were implemented with luminescent diodes [10] and photo-transistors [11]. The signal taken from the photo-transistors is compared with two thresholds that can be adjusted by varying the potentiometers values (R_5, R_6).

The outputs Y0, Y1 of FX3G will command two electro-valves that will send the objects from the conveyor in the containers.

2.1. ProgramMING THE SYSTEM FOR SORTING OBJECTs by size

The program was written by using the development medium GX Developer from Mitsubishi Electric [12]. The following devices were used:

- X1, X2 – optical barriers
- Y0, Y1 – electro-valves with air under pressure
- T - temporizations
- M – 1 bit memory locations

The ladder diagram from the figure 4 is made for detecting small size objects. In the program line 0 when the objects arrive on the level of the first optical barrier then M1=1. After a time T1, the electro-valve Y0 will be actuated and it will be maintained in an open state an interval of time T3.

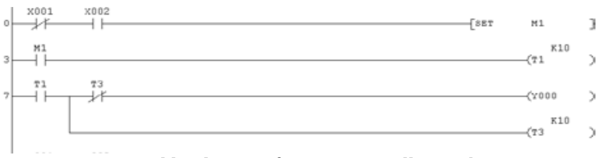

Fig. 4 Ladder diagram for sorting small size objects

When the large size objects arrive on the level of the second optical barrier then M2=1 (program line 15 in figure 5). After a time T2, the electro-valve Y1 will be actuated and it will be maintained in an open state an interval of the time T4.

Fig. 5 Ladder diagram for sorting large size objects

3. SORTING BY OBJECT COLOR

The devices for sorting objects based on their color are often met on the production lines in industry. They detect the colors of the objects by their passing in front of the sensor and then, depending on the program preset by the users and using electrically actuated devices (palettes, gutters) or pneumatics (compressed air nozzle) the objects are directed in the appropriate places.

The TCS230 color sensor was used in the sorting system implementation. The sensor consists in a programmable color light-to-frequency converter that combines configurable silicon photodiodes and a current-to-frequency converter on a single monolithic CMOS integrated circuit [13][18].

In figure 6 is presented the experimental stand for sorting objects by their color feature.

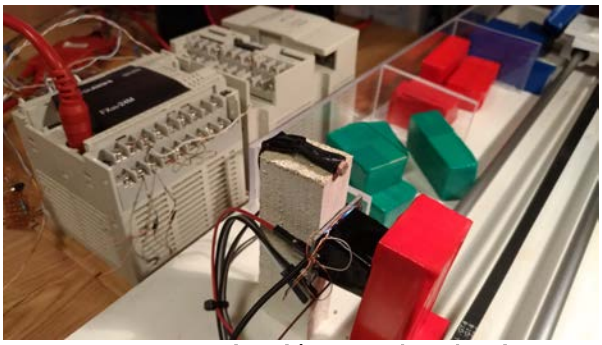
Fig.6 Experimental stand for sorting objects by color

In order to obtain good results it is important for the sensor to receive only the light reflected by the colored object. So, it is necessary to have an optical insulating from the exterior light that could reach on the sensor (figure 7).


Fig.7 TCS230 Color sensor and its mounting scheme

The electric scheme for connecting the color TCS230 sensor to FX3G PLC is presented in figure 8.

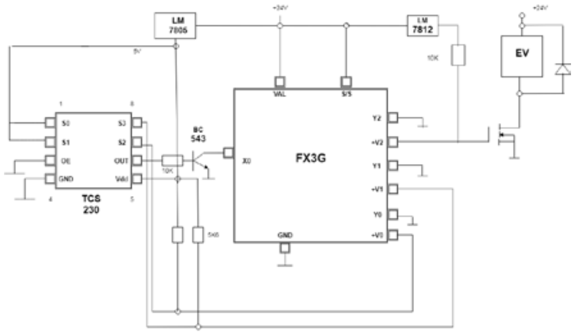

Fig.8. Electric scheme of sorting system based on object color

The output frequencies S2 and S3 are controlled by to logic inputs, S0 and S1. The internal converter light – frequency generates a train of pulses with fixed period. Scaling is done by the internal connection of the output pulse train to a series of frequency dividers.

For selecting the RGB filters the command for S2, S3 pins are used as in table 1 [13].

Table 1 -Selectable options for S2, S3

S2	S3	Photodiode type
L	L	Red
L	H	Blue
H	L	Clear (no filter)
H	H	Green

3.2 PROGRAMMING THE SYSTEM FOR SORTING OBJECTS BY COLOR

The following devices were used:

- X0 – frequency signal reading
- Y0, Y1 – color filters S2, S3 selection
- Y2, Y3, Y4, Y5... – electro-valves
- T – temporizations
- M – 1 bit memory locations
- D – registers on 16 bit

The ladder diagram for setting the color filter and measuring the frequency is given in figure 9 (line 0).

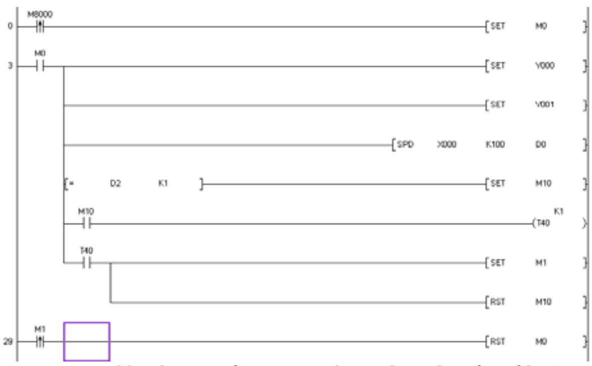

Fig. 9 Ladder diagram for sorting objects by color (first filter)

The SPD instruction measures the frequency given by the sensor and the result is memorized in D0 register [14]. The current value of the remained time until the finalization of the conversion is given in the D2 register. At the end of the conversion, the frequency reading for the next filter is started (figure 10- line 32).

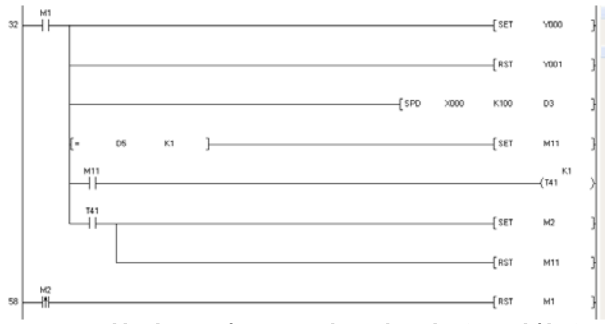

Fig. 10 Ladder diagram for sorting objects by color (second filter)

The three RGB color filters will be set successively, including "no filter" situation, in order to obtain all color components.

The values that are read from the color sensor are memorized in registers D0, D6, D9. With these values the RGB color components will be calculated (relation 1) by the using the TCS230 color correction matrix [15]:

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 0.7659\ 0.7052 - 0.4990 \\ -0.3140\ 1.3283 - 0.1367 \\ 0.0609\ \ -0.4739\ 1.0326 \end{pmatrix} * \begin{pmatrix} D0 \\ D9 \\ D6 \end{pmatrix} \quad (1)$$

So for computing the red component (R) the ladder diagram will be that from the figure 11.

Fig. 11 Ladder diagram for computing the red (R) component

Similar calculations will be done for green (G) and blue (B) components. The values obtained are normalized and compared with the reference values, and depending on the color information the outputs commands for the electro-valves are given (figure12).

There were tested three colors and the results that were obtained in registers D50, D52, D54 are listed in table 2. RGB tables of conversion may be used for the color confirmation [16]

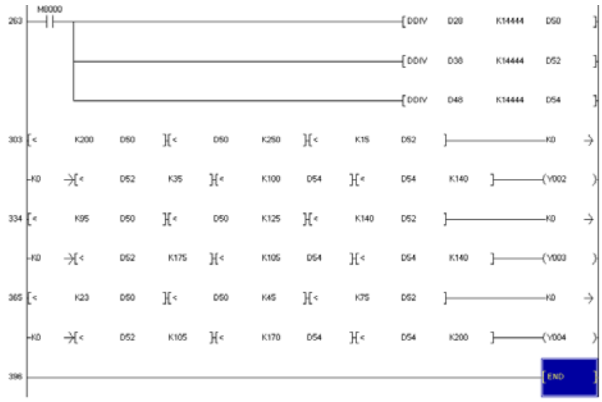

Fig. 12 Ladder diagram for electro-valves control

Table 2-RGB components obtained for three different colors

	R	G	B
1	236	21	126
2	106	158	117
3	35	95	196

4. CONCLUSIONS

The work proposes an application for sorting objects based on their size and color and it is implemented on a PLC. The solution proposed is reliable, has a great speed of execution and reasonable cost price compared to other sorting systems that use expensive data acquisition and processing systems. The frequency measurement is made in 0.1 seconds with a resolution of four digits.

The application can be integrated in a multi-feature e-waste intelligent sorting system.

5. ACKNOWLEDGMENTS

This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI-UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0652 / 84PCCDI/2018, within PNCDI III.

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