COLORIMETER FOR FRUIT SORTING SYSTEM

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Abstract: The present paper proposes a study, followed up by the implementation of a low cost and low power consumption fruit sorting system. The implemented system was tested for apple sorting. Under the tests we gained an accuracy of 100% from the correct sorting point of view, which emphasize the good functioning of the system proposed by us.

Keywords: *colorimetric, microcontroller, RGB LED, photoresistor*

I. INTRODUCTION

Fruits and vegetables are checked before processing operations or before packing. Nowadays sorting operations are performed with an optical or electronic technology, unlike in the past when it was performed manually through visual inspection. Back than each worker had to verify hundreds of elements per minute and to sort them manually. In order to fulfill this task good lighting conditions were needed. Inadequate lighting led to worker fatigue and eyestrain, therefore the sorting efficiency was very poor.

Three major components interact in the visualization process of a colour: light energy from a lamp or a luminaire, the reflection potential of a fruit's colour, called spectral reflectance and eye sensitivity to colour, called receiver's sensitivity. Out of these three major components, the light source is the easiest to control. For example, in order to "see" the red color we must have a light source that contains the red color, a surface that reflects the red color and a receiver sensitive to the reflected red color. The natural light source is the sun, which can play all visible colours.

The spectral reflection of a fruit is in fact the capacity of the fruit to reflect certain colours in the presence of natural light. For fruits, chlorophyll or other natural pigments give the fruit's colour. In the circumstance of manual sorting, the human eye is the receiver, the disadvantage being the fact that the human eye can't be adjusted.

In present days most producers from all over the world create sorting machines for fruits, these being classified depending on colour, size, weight. Among these producers Compac Sorting Equipment are listed. Established in 1984, Compac Sorting Equipment is a world leader in the development, supply and manufacture of intelligent solutions and equipment for fruits sorting. Compac sorting technology is the solution to all sorting requirements of apples, being chosen by numerous factories from all over the world, as it is easy to use and the software by colour classification is used for 6 or more colour classes. Compac colour system is designed to perform at speeds of up to12 fruits per second. This system can sort apples by weight, colour, internal quality and flawless.

One of the most accurate and easy to use Invision Compac sorting system by color is 5000, which is preferred by the U.S. (40%). Compac Invision 5000 captures multiple images of fruit at standard production speeds up to 15 fruits per second. This colour sorting system is unique because the software is easy to use having advanced features; multiple images (up to 30 images) are captured for each fruit for better accuracy. This model performs the evaluation of fruits depending on many properties, such as: colour (up to 16 different colours), hue, form, diameter, volume, etc.

All these systems are based on powerful computer systems which has to do a large number of computations on the captured images with CCD cameras.[2][3][4][6] To reduce the number of computations artificial intelligence algorithms are tested.[7] These systems are very expensive and use a lot of electrical power. In the study that we propose in this paper we bring a possible future alternative to these systems.

II. THEORETICAL FUNDAMENTALS

Absorption is the phenomenon of energy attenuation of electromagnetic radiation during its passage through a transparent medium. The energy that is absorbed by the medium is converted into other forms of energy. The absorption is selective, depending on the nature of the absorbent environment and the wavelength of the light wave, so the glass does not absorb visible radiation, but absorbs infrared and ultraviolet.

Light absorption explains the colour of the bodies. In this way transparent bodies absorb radiation of all wavelengths except those that determine the colour filter, while opaque bodies absorb all wavelengths except those reflected that determines body colour.

When the light falls on the object, not all the light is reflected, but part of it can be absorbed by the object, and a part can be transmitted through the object (Figure 1).

Manuscript received October 17, 2014; revised December 2, 2014

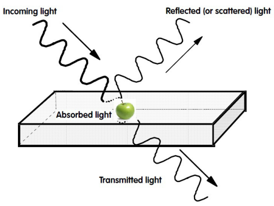

Figure 1. Reflexion, absorption and light transmission of an object.

On the above statements we can conclude, that the three processes mentioned must represent all the incident light flux on the object.

$$\Phi_I = \Phi_R + \Phi_A + \Phi_T \tag{1}$$

where : Φ_I is the incident light flux, Φ_R is the reflected light flux, Φ_A is the absorbed light flux, Φ_T is the transmitted light flux.

Equation (1) is part of the principle of physics, called energy conservation, which says that energy can not be created or destroyed. Many solid objects do not transmit a lot of light through them, such that equation (1) becomes simpler :

$$\Phi_I = \Phi_R + \Phi_A \tag{2}$$

All the light which is not absorbed by the object has to be reflected by the object. For example, if an object does not absorb light, all the light will be reflected, and our eyes will see the white object (Figure 2).

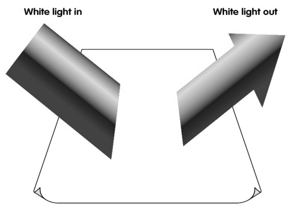

Figure 2. The light is not absorbed by the object, white color appears.

On the other hand, if all the light that falls on an object is absorbed, there won't be reflected any light, and our eyes will see the black object (Figure 3).

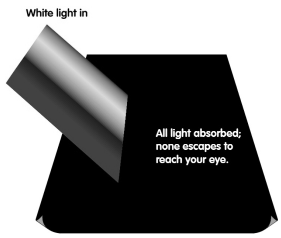

Figure 3. Light is all absorbed by the object, black colour appears

The case when only a few colours are absorbed. For example, if a fruit absorbs violet, blue, green, yellow, orange and does not absorb all the red light, the fruit will be red (Figure 4). If you have a tomato and a red apple we need more clues, like form, to say exactly where the fruit is an apple or a tomato.

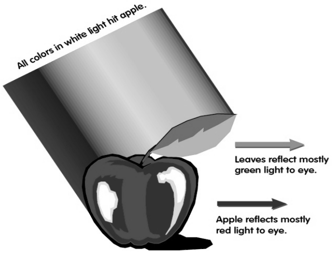

Figure 4. Apple and leaf colour depending on absorption.

III. IMPLEMENTATION

The main parts of any sorting system of fruit or vegetable are the carrying assembly and the detection system. Usually the detection system is hold in a chamber, which offers a proper medium for all the sensors used in the classification process.
The whole sorting system is shown in figure 5:

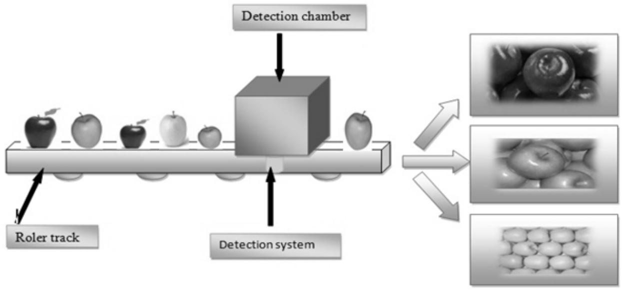

Figure 5. Sorting system example.

The most common classifying systems are based on colour and dimension detection. These parameters are the essential ones to determine the quality of a product (fruit or vegetable). Our work from this paper is concentrated on the implementation of a sorting system based on the colour of the products. Mainly the apples where used to prove the validity of the system, because we could acquire these fruits in all the seasons in a lot of variety of colors and dimensions. The main building blocks of our system are presented in Figure 6. The sensor implemented is based on the principals of absorptions presented in the theoretical fundamentals. For this approach we need a light source for the incident light flux and a photodetector to measure the reflected light flux.

Figure 6. Building blocks of the detection system.

To respect the low power consumption imposed for our system we focused on the LED light sources which offer, among, the already well known, very low power consumption a long lifetime too.

Instead of exposing to white light the fruit to be sorted, we exposed it to three basic color spectrum : red, green and blue. Because of the spectrum emitted by LEDs, the combination of these three spectra can produce white light. To reduce the complexity of the system, in the place of regular single chip LEDs we used the three-chip RGB LEDs. With a proper driving of these LEDs we can obtain the entire visible spectrum.

From the large market of LEDs we analyzed a few of them: HB5-40AORAGCABCC, IF-5WAEMBGMBC, LF-79WAEMBGMBC, IL-F506RGB2E-F1, OSTF5131A.
A key point in choosing the right LED was the need to have a Gaussian type of light emission. Taking into account this demand we chose the HB5-40AORAGCABCC which has the smallest view angle of half power; in this case 12°. The electrical characteristics of this LED are summarized in Table 1.

Table 1. Electrical parameters of HB5-40AORAGCABCC

Parameter	**Red**	**Green**	**Blue**
Forward Voltage (V_F) [V]	2	3.2	3.3
Continous Forward Current (I_F) [mA]	25	25	25
Peak Forward Curent (I_{FM}) [mA]	50	100	100

For the data processing unit we picked a microcontroller from the AVR family, Atmega 8L-8PU. The features of the outputs of this unit allowed us to use it for the LED driver too, reducing in this way the overall additional circuits. The first attempt to drive the RGB LED was like the one from Figure 7 where we used the PWM command straight out from the microcontroller to the LED. Unfortunately in this manner the light output was too low for our needs.

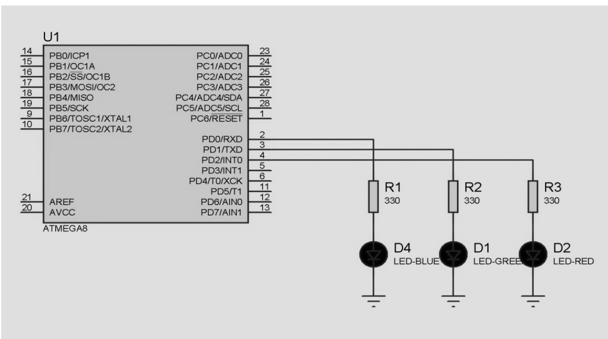

Figure 7. LED driver circuit.

To increase the light output we had to increase the current. Because the maximum output current from each microcontroller output is maximum 20mA, we designed an auxiliary circuit for current amplification. The adjacent circuit is presented in Figure 8.

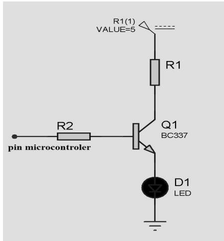

Figure 8. LED driver using bipolar transistor.

In the above circuit the bipolar transistor works as a switch between the blocking mode and saturation mode. The npn BC337 transistor fulfilled our demands. The value of resistor R_1 can be calculated with:

$$R_1 = \frac{V_{CC} - V_{FM} - V_{CEsat}}{I_F} \tag{3}$$

Using relation (3) with: the electrical parameters from Table 1, for each semiconductor chip from the RGB LED, a peak current I_{FM}=30mA, a reference voltage V_{CC}=5V and knowing that $V_{est} \approx 0.2$V we obtained the following values in each case: R_1=100Ω for red light emitting chip and R_1=50Ω for the green and blue light emitting chips. To ensure a good switching of the transistor R_2=1k Ω.

For the photo detection module of the sensor we focused on a photoresistor, because the responsivity of these devices is very close to that of the human eye. The main problem with the photoresistors is the high sensibility to any kind of optical wavelengths from the visible spectrum. Also, theirs sensibility depend on the distance from the light source. To get read of this undesired effects we had to place the sensor assembly (RGB LED, photoresistor) in a dark chamber, where the only light comes from the LED. The light from the LED will interact with the fruit and the reflected light is captured by the photoresistor. Thus, we oriented the LED and the photoresistor in an angle that they cannot interact in a direct mode and the distance from LED and photoresistor to the fruit to be constant. To achieve the last one we created a special cavity which hides the sensor assembly (Figure 9).

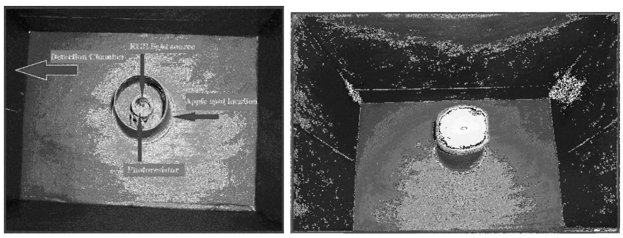

Figure 9. Detailed view of the detector chamber.

We took in consideration a large variety of photoresistors, like : A906012, FW300, M996011B, VT93N2, FR12/100K. We selected the FR12/100K in our experiment, because it has a larger surface to capture the reflected light. To have a good response on this photoresistor it must be exposed to light for at least 35ms. To reset de value after exposure to light, the photoresistor must stay in full darkness for a minimum of 5ms.

To read the value of the photoresistor and to process this information in the microcontroller, we used the circuit from Figure 10.

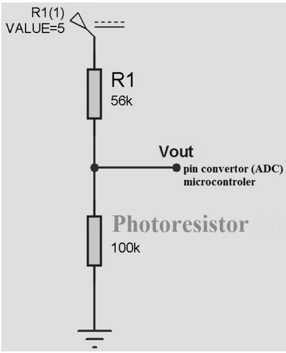

Figure 10. Light detection with photoresistor.

The circuit works as a voltage divider, where the variation of photosensitivity's value will lead to different current and implicitly to a different voltage on the photoresistor. This voltage value will be the input signal to be processed by the microcontroller. The voltage to be read respects the relation:

$$V_{out} = \frac{R_{PR}}{R_1 + R_{PR}} * V_{CC} \qquad (4)$$

where V_{CC}=5V, R_{PR} – photoresistor.
To have a good reference voltage across the photoresistor, we tested the circuit with different R_1 : 10kΩ, 27kΩ, 56kΩ, 100kΩ. Withal, we used different exposure times for the photoresistor. We used the red, green and blue light. From all the measurements made we looked for the ones that offer a better distribution between the maximum and minimum output voltage. The resistence R_1=56kΩ fulfilled our requirement and the measurements obtained with this one are concentrated in Table 2.

Table 2. Direct measurements between RGB LED and photoresistor, using circuit from Figure 9 with R_1=56kΩ.

Exposure time (ON/OFF)	Red		Green		Blue	
	V_{min} [V]	V_{max} [V]	V_{min} [V]	V_{max} [V]	V_{min} [V]	V_{max} [V]
5s/5s	0.226	3.60	0.172	4.08	0.271	3.85
1s/1s	0.226	2.48	0.175	2.77	0.273	3.70
0.5s/0.5s	0.228	2.38	0.177	2.62	0.620	2.27
100ms/100ms	0.249	1.13	0.207	1.06	0.737	1.80
50ms/50ms	0.489	0.534	0.441	0.481	0.807	0.880

The voltage measured across the photoresistance is memorised and processed by the analog to digital convertor (ADC) from the microcontroller. The digital value of the input voltage is calculated by dividing this voltage to the value of the V_{LSB} (least significant bit). Having a resolution of 10 bit, the value of V_{LSB} is:

$$V_{LSB} = \frac{V_{CC}}{2^{10}} \qquad (5)$$

After having all three measurements, for red, green and blue light exposure we look for an algorithm to identify the correct color of the fruit.
To display the final result of the sorting we used an alphanumeric LCD connected to the microcontroller.
The entire schematic of the electric circuit of the proposed calorimetric based sorter is presented in Figure 11, in the Proteus software medium.

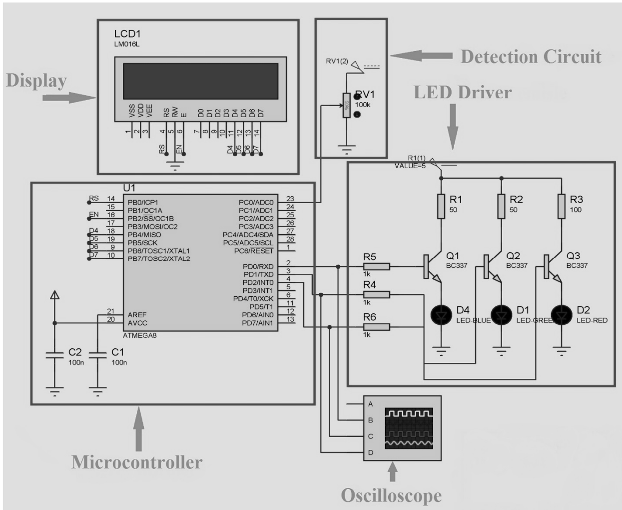

Figure 11. Electrical circuit of the proposed system.

IV. EXPERIMENTAL RESULTS

The prototype of the implemented system is presented in Figure 12. The exposure time of the photoresistor was controlled by software.

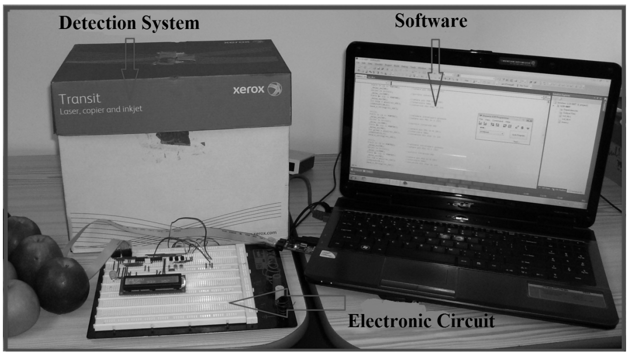

Figure 12. The prototype of the sorting system.

To determine the sorting algorithm, we made many measurements on different sets of apples. One of these sets is presented in Figure 13, where we have 10 apples from each colour: yellow, green and red, and each apple having different dimension.
The first exposures were made for a period of 1s in lighting conditions and 1s in darkness. The values obtained in this process are summarized in Table 3, Table 4 and Table 5, where V_R,V_G, and V_B are the voltages obtained across the photoresistor at the exposed red, green and blue light.

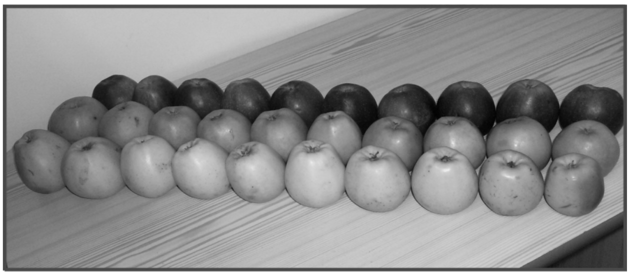

Figure 13. One set of apples used for sorting.

From this results we can find an easy and very effective relation to determine the right colour of the apples :

- Yellow apple for : (V_R<V_B) & (V_B<V_G) & (V_R<V_G) ;
- Green apple for : (V_B<V_G) & (V_G<V_R) & (V_B<V_R) ;
- Red apple for : (V_R<V_G) & (V_G<V_B) & (V_R<V_B).

Table 3. Measurements on yellow apples

	YELLOW APPLE					
	Exposure period (light-darkness) 1s/1s			**Exposure period (light-darkness) 50ms/50ms**		
	V_R[V]	**V_G[V]**	**V_B[V]**	**V_R[V]**	**V_G[V]**	**V_B[V]**
1	1.90	3.14	2.44	2.02	2.48	2.20
2	1.82	2.98	2.28	2.03	2.42	2.22
3	1.71	2.66	1.92	2.27	2.67	2.49
4	1.63	2.38	1.68	2.02	2.20	2.07
5	1.66	2.57	1.80	2.04	2.30	2.24
6	1.69	2.55	1.76	2.08	2.41	2.20
7	1.60	2.31	1.61	2.57	2.86	2.61
8	1.74	2.66	2.12	2.40	2.81	2.66
9	1.66	2.62	2.13	2.20	2.59	2.51
10	1.66	2.60	1.84	2.11	2.45	2.30

Table 4. Measurements on green apples

	GREEN APPLE					
	Exposure period (light-darkness) 1s/1s			**Exposure period (light-darkness) 50ms/50ms**		
	V_R[V]	**V_G[V]**	**V_R[V]**	**V_G[V]**	**V_R[V]**	**V_G[V]**
1	2.54	2.46	1.80	2.83	2.38	2.33
2	2.55	2.25	1.73	2.75	2.52	2.39
3	2.47	2.43	1.86	3.03	2.68	2.59
4	2.63	2.60	2.07	2.91	2.64	2.51
5	2.76	2.21	1.88	2.53	2.52	2.29
6	2.78	2.62	1.95	2.89	2.63	2.42
7	2.63	2.53	1.96	2.93	2.59	2.53
8	2.64	2.62	2.01	3.00	2.69	2.63
9	2.69	2.45	1.89	2.86	2.55	2.51
10	2.88	2.59	2.13	3.07	2.90	2.78

Table 5. Measurements on red apples

	RED APPLE					
	Exposure period (light-darkness) 1s/1s			**Exposure period (light-darkness) 50ms/50ms**		
	V_R[V]	**V_G[V]**	**V_R[V]**	**V_G[V]**	**V_R[V]**	**V_G[V]**
1	2.28	3.06	3.58	2.92	3.15	3.68
2	1.93	2.64	3.22	2.93	3.28	3.71
3	2.01	2.81	3.50	2.73	3.05	3.48
4	2.54	2.88	3.48	3.08	3.36	3.70
5	2.57	3.21	3.54	3.33	3.43	3.82
6	2.02	2.65	3.31	2.90	3.15	3.65
7	1.99	2.83	3.42	2.88	3.18	3.64
8	2.31	3.04	3.57	2.98	3.32	3.67
9	2.13	3.06	3.56	3.01	3.37	3.73
10	2.56	3.55	3.69	3.21	3.49	3.77

Having the algorithm for sorting, we tried to use a smaller exposure time to have a quicker sorting system. For that, in the next experiment we reduced the exposure time to 50ms for lighting conditions and 50ms to darkness. The new results can be found in the same tables where the first exposure times are listed.

It can be seen that the measured voltages for each emission colour are reduced against the first experiment, but the sorting algorithm remains the same. This is very encouraging because sorting time was halved. In this case the overall exposure time for one fruit is 300ms. We can see this on the LCD panel too. We can say that our sorting system can sort a number of 200 fruits/min.

The good results with the prototype lead us to the PCB implementation of the electrical circuit, as it is captured in Figure 14.

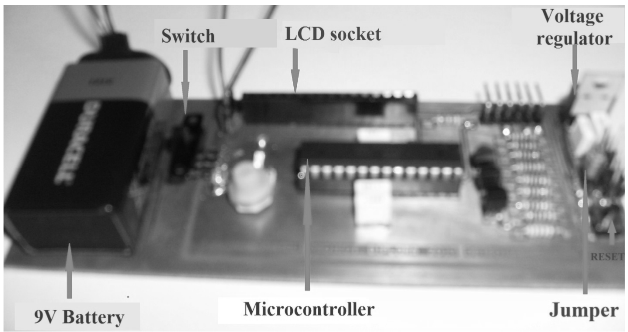

Figure 14. The final version of the sorting system without LCD panel.

The power supply voltage for all the modules (LED driver, photoresistor circuit, microcontroller, LCD) is 5V. Thus, we can power up our system from a USB port or even from a battery. To switch between the two power options we used a jumper and a 5V voltage regulator when using the battery system. The LCD panel is connected, in the provided socket, in a manner that reduces the implementation area (Figure 15).

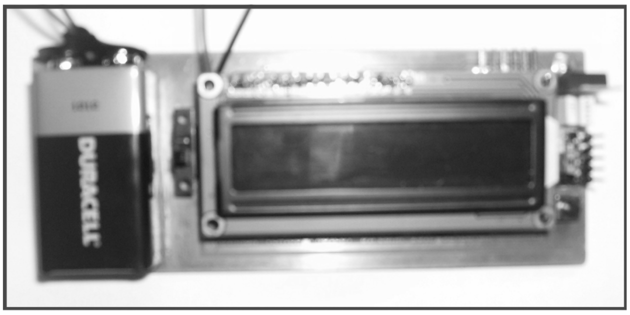

Figure 15. The final version of the sorting system with LCD panel.

CONCLUSIONS

In the food industry the quality of fruits and vegetables are analyzed mainly by colour and dimension. [5][7][9] In present, all the sorting machines use image capturing and processing systems. The brief functioning features of these systems can be found in [8]. These kinds of systems are very expensive for most of the farmers.

In this paper we proposed a new sorting system based on low cost and low power electronic devices. The system uses reflectivity and absorption principles, where the natural light is replaced by LEDs and the human eyes by photoresistences.

The sorting algorithm used by our system is a simple and very efficient one, having an accuracy of 100% on the tested apples. In the close future the testing will be done on a larger variety of apples from their colour point of view.

The power consumption estimated is around 0.5W, but future work will be engaged to determine the exact consumption.

If in an expensive computer vision assisted machine the speed of sorting is 1000 products/min [10], our system has a speed of sorting of only 200 apples/min. The speed of sorting is in attention on future work.

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