TWO-DIMENSIONAL MATRIX DISPLAY OF RGB LEDs

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***Abstract*— LED matrix displays have a common vision today, they can be very bright eye-catching, and its information easy to absorb. The displays are commonly seen in a single color or with 2 or 3 colors. In this article are introduced the multicolored LED displays. This project provides an efficient and scalable approach to LED matrix displays. The proposed system consists of an RGB LED array and a circuit to interface with a computer via USB or wireless communication. It also includes a program that runs on a computer to control the display of characters or images on the display. Another important feature is the use of an RGB light sensor for adjusting the color, according to the sensitivity of the human eye in different environments. The advantage of this project is that the size of the display can be increased along the rows and columns without making any changes to the circuit since the display is the repetition of small independent modules.**

***Keywords*— LED Panel, matrix display, multicolored, RGB, scalable.**

I. INTRODUCTION

During the last decades the Light Emitting Diode (LED) technology has dramatically improved and the world of LED image faced an impressive revolution. Particularly in recent years, new production techniques have been developed to increase the brightness and reduce decay. All these innovations allow the panels to remain in operation for over 10 years without changing the LED's.

The rapid acceptance of this technology over existing image display technologies can be attributed to the availability of green and blue high-brightness LED technology based on gallium nitride and indium, complementing the red high-brightness previously available.

The strengths of LED technology are the highly visibility both day and night, long service life, high reliability and resistance to environment, low power, low weight and thickness, large power range and variety of color spectrum.

By reducing the price of LED's together with increased efficiency, the panels of image, video and alphanumeric displays are becoming a very important tool of information. This technology presents itself as a good way of large visual information where the large LCD and other screens become too expensive. It offers a wide viewing angle, a great brightness and an image suitable for outdoor application.

The system of an electronic display is basically comprised by different sources of video/image signals attached to a unit controller (microprocessor) and a large display composed of an array of independent modules with dimensions that vary by manufacturer and model. Each module has an array of dots (pixels) were formed, each one, by red, green and blue LED's (standard RGB), which gives a complete presentation of the color spectrum, also known as full color.

The panels are normally used outdoors, on screen advertising, sports, information boards and road signs. They are also sometimes used as a means of illumination.

II. STATE OF THE ART

There are two types of LED panels [1] — conventional, using discrete LEDs, and SMD (Surface Mount Device) panels.

Most outdoor screens and some indoor screens are built around discrete LEDs, also known as individually mounted LEDs. A cluster of red, green, and blue diodes is driven together to form a full-color pixel [1].

Most indoor screens on the market are built using SMD technology, a trend that is now extending to the outdoor market. An SMD pixel consists of red, green, and blue LEDs mounted on a chipset, which is then mounted on the printed circuit board [2]. Since these LEDs are smaller and are closer together, the maximum viewing distance is smaller in relation to a screen of discrete LED's with the same resolution.

Indoor use generally requires a screen that is based on SMD technology and has a minimum brightness of 600 candelas per square meter (cd/m²) [3], which is usually more than sufficient, but under high ambient-brightness conditions, may be need more brightness for good visibility.

For outdoor use, at least 2000 cd/m² is used for most situations, and a brightness of 5000 cd/m² allows viewing even in direct sunlight [4].

Currently the technology of LED screens has greatly evolved and there are high definition displays that allow playback of high quality digital video, with a supported range of colors amounting to 1 billion colors [5]. The largest LED screen in the world has a length of 400m and is located in the Fremont Street Experience in Las Vegas.

Nationally, the company *Fatrónica – Fabrico de Artigos Electrónicos*, *S.A.* and the company *Microprocessador Sistemas Digitais, S.A.* produces a wide range of panels using LED technology for use primarily in road signs.

Table 1 shows the main characteristics of the variable message LED panels of *Microprocessador*, used in road signs [6].

Table 1 Characteristics of variable message signs of the *Microprocessador*.

Communication interfaces	• RS232 / RS485 • Ethernet • GSM/GPRS • WiFi • USB
Communication protocols	• Web Server for remote configuration • TCP/IP e SNMP • DGT
Mechanical	• Modular architecture • Steel or aluminum • IP55~IP65
Sign Configuration	• Text and Graphics • LED technology DIP/SMD • Monochrome, RGB and other color combinations
Power Supply	• AC 230 V 50 Hz or 110 V 60 Hz • DC 24 V • 24 V battery and intelligent charger optional
• Non-volatile memory for pre-programmed messages	
• EN 12966 compliant and CE conformity	

The characteristics of a LED screen for video display of *Shenzhen Chip Optech Co*. [7] are shown in Table 2.

Table 2 Features of LED display PH16SOVL1-T16x8.

Pixel configuration	1R, 1G, 1B
Pixels pitch [mm]	16
Module size [mm]	256x128x20
Module resolution [pixel]	16x8
Module quantities in a cabinet	4(L)x6(H)
Weight [kg/cabinet]	Aluminum: 42
Pixel density [pixel/m^2]	3906
Brightness [cd/ m^2]	≥ 5500
Color temperature [K]	5000-9500
Brightness adjusted	100 grade
View angle	H: 110º; V: 70º
Best viewing distance [m]	> 11
Communication distance [m]	Wire: 120; Fiber cable:1000
LED driving method	Constant current
Bits per color	14
Refresh frequency [Hz]	≥ 400
Input signal	VGA, Svideo, DVI
Working temperature [ºC]	-20 ~ +60
Humidity	10-95 %
Screen lifetime [hours]	≥ 100 000
Power supply	AC: 220 V/50 Hz
Power consumption [W/m^2]	Max: 1050

III. Objectives

The purpose of this study is to develop a prototype of a display with high brightness RGB LED's and brick structure with basic building blocks of 16x16 sets of RGB LED's. This screen makes it possible to display both alphanumeric characters as bitmap images, and can be used in a wide variety of applications.

The system uses hardware and software to allow the partition of an image into blocks of 16x16 pixels and the excitement of the corresponding LED's, using microcontrollers and local image memory.

The intensity of LEDs and the color is adjusted according to the sensitivity of the human eye on environment day and night, using for it an RGB light sensor and control algorithms of the LED's.

The modular structure allows making panels with high resolution, without changing the circuit, by association of identical modules. Communication with the modules is done through a central controller which possesses wireless interface and USB for receipt of images from a PC controller.

Fig. 1 represents the block diagram of the entire system.

This work has the support of the company *Fatrónica – Fabrico de Artigos Electrónicos, S.A.*, which already has many years of experience in the field of electronic displays.

To achieve the proposed objectives were accomplished the following activities:

1. Preliminary research of technologies for LED panels, architectures and applications by searching the Web sites of manufacturers, magazines, articles and books;
2. Development and assembly of the LED matrix;
3. Development and construction of the controller board for the module;
4. Implementation of the firmware for the controller board;
5. Development and construction of the central controller;
6. Implementation of the firmware to the central controller;
7. Implementation of software running on the PC;

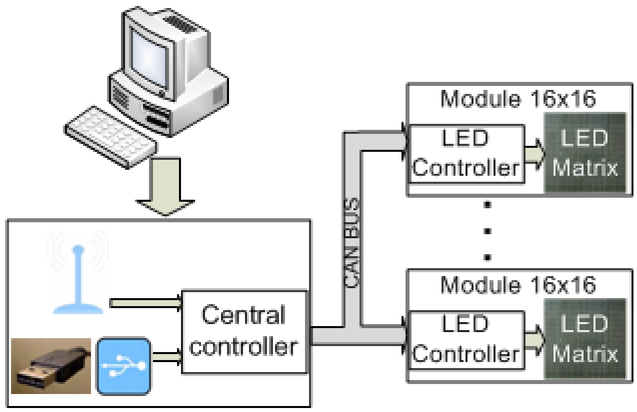

Fig. 1 Block diagram of the complete system.

IV. System Overview

A. Led matrices

With the growing number of LED's to control, the resources needed to operate these LED grow to an unmanageable level. As such, they are often arranged in matrices [3], in order to make efficient use of resources. In a matrix form, the LEDs are arranged in rows and columns. What is mainly due to cost, because it needs a small number of control elements, but also the limited interconnections and simplicity of design of printed circuit board.

Each column of the array is activated sequentially during a period of time that is called scan period [8]. In each scan period are also activated the lines corresponding to LED's that want to connect [9].

The frequency at which each column is activated is called the refresh rate. If this frequency is high enough, the human eye does not see the transition, noting only one set of LED's lit as if they were connected simultaneously [8].

B. Brightness control

To control the brightness of the LED's are mainly two options: analog variation and variation by modulating the pulse width (PWM). As the light produced by an LED depends on the current flowing through it, the analog variation controls the brightness of the LED by linear changing of the current in the LED.

However, in LED screens is used the variation by PWM due to the change in current of the LED affects the wavelength of light emitted, as shown in Fig. 2 [10] for the case of a blue LED.

Detecting a change of a few nanometers in an LED is difficult for the human eye, but a change in color temperature of white light, however, is easily detected. PWM variation ensures that the LEDs emit an accurate color, regardless of intensity. This precise control is especially important in RGB applications where the light of different colors is mixed to produce white.

Through PWM the changes in the brightness of the LED are obtained by varying the duty cycle, that is modulating the fraction of time during which current flows for a period [11]. In other words, the LED is turned on and off quickly.

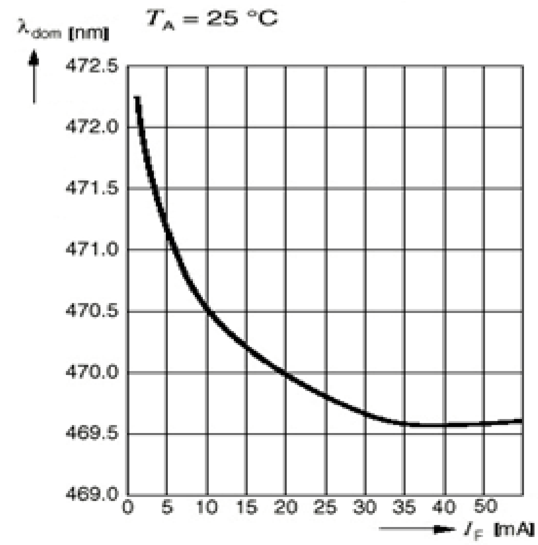

Fig. 2 Relationship between the wavelength and a blue LED current.

If the switching frequency is greater than 50 Hz, the human eye does not see the LED on and off, instead he perceives a reduced brightness that is proportional to the duty-cycle. For LED displays is recommended a refresh rate above 60 Hz [8].

PWM variation generates a number of discrete levels of brightness for each LED. The total number of discrete steps available throughout a period determines the resolution of the brightness of the LED. Displays of high quality require hundreds to thousands of steps of brightness to accurately reproduce the full spectrum of colors required for video playback. Each pixel in a color screen is composed by three LEDs: red, green and blue. If each color has 256 steps of brightness, the RGB set is capable of producing a palette of more than 16 million colors.

However, the control system of the LED matrix will activate an entire column at once. To control the brightness of each LED is necessary to divide each scan period in time slots depending on the number of brightness levels [8].

V. Hardware

A. LED Module 16x16

LED module 16x16 is the core of the display. Each of these modules is composed of a matrix of 256 red LEDs, 256 green LEDs and 256 blue LEDs.

For the formation of a pixel were preferred 3 individual LEDs of each color instead of a single RGB LED. Although both have the same maximum current, the luminous intensity of individual LEDs is higher, and the forward tension is lower allowing lower supply voltages. Moreover, the individual LEDs occupy a larger area, which standardizes the light in the module since there are fewer empty spaces.

The LED's that make up a pixel are arranged in a triangular shape and inverted in relation to the pixel at his side, as shown in Fig. 3. This setting causes the module to present a uniform color throughout the matrix.

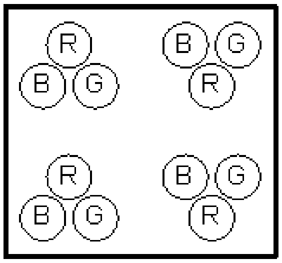

Fig. 3 Organization of LEDs on the modules.

The spacing between each pixel is 16.4 mm, corresponding to modules of 26.2 cm in height and width, as including the distance between the edge of the module and the nearest pixel. The display will consist a maximum of 16 modules, reaching a height and width of 1.05 m and a resolution of 64x64 in accordance with EN 12966 [12], thus enabling the integration in road signs.

Lifetime of LED's

One of the main characteristics of LEDs is their potential too long lifetime. Under normal operating conditions (25 ºC and 20 mA current), the LEDs have a life expectancy on average, about 100,000 hours. If they operate for 12 hours a day, the lifetime corresponds to more than 22 years.

The *Alliance for Solid State Illumination Systems and Technologies* (ASSIST), a group led by the *Lighting Research Center* (LRC) recommended the definition of useful life of an LED as the point at which the luminous flux decreases to 50% of initial lumens (abbreviated as L50) for LEDs used in this applications [13].

One factor that has a direct impact on life expectancy of the LED is the operating current. If a LED is operated at reduced current his life is further extended, on the other hand, operating an LED at current above the nominal increases the production of light, but decreases its lifetime. If used in a hot environment, or an enclosed area, the heat will also decrease its lifetime.

B. Module control board

The module consisting of the LED array is also coupled to a board which is designed to control the rows and columns of the matrix, as well as control of brightness of each LED. This board performs too the communication via CAN bus with a central controller receiving the data to be presented in the module.

To control the brightness of the LEDs is used the intelligent controller TLC5944 [14]. It is a constant current controller with 16 channels and a maximum current of 70 mA each.

Each channel is individually adjustable with 4096 PWM steps and 64 constant current levels (dot correction), allowing adjust the brightness variations between LEDs. Both brightness controls and dot correction are accessible via a common serial interface at a maximum frequency of 30 MHz.

The LEDs used support a maximum current of 30 mA, but was fixed a maximum current of 25 mA to be a safe value, and high currents also reduce the life cycle of the LED.

The selection of the columns of the array does not require a very specific controller, just a port expander, such as MAX7301 to select the desired column via serial communication.

The control board of the LEDs is shown in Fig. 4.

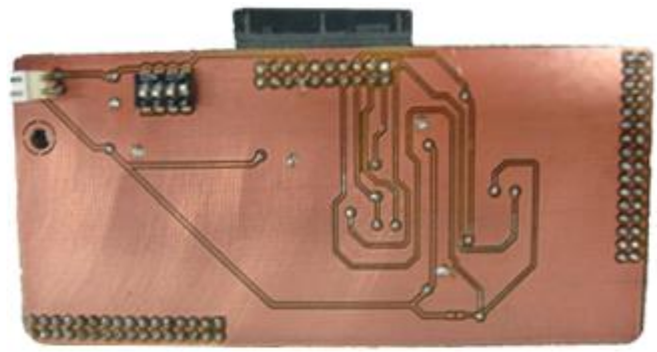

Fig. 4 LEDs control board.

Each module has the ability to be autonomous and independent of the other, allowing operation even in case of failure of any block of the system. This feature allows the display continues to display the images even if one of the modules has a failure or the communication with the central controller is interrupted. To make this possible is used a microcontroller dsPIC30F6012A in each module for data processing.

C. Central controller

The data sent by a computer to be displayed across the entire display, are received by this block of the system via wireless or USB. After partition of the data, they are sent via CAN bus to the corresponding modules.

Regardless the *Microchip* microcontrollers not have simultaneously communication USB and CAN, the choices were based on microcontrollers from this manufacturer because there are already tools for programming and development, also used for the microcontroller of LED module.

To achieve the desired communication interfaces, was used the converter of CAN to SPI MCP2515 and was selected the microcontroller PIC18F4550 with integrated USB communication.

The prototype of the central controller is shown in Fig. 5 and was developed with only 6.5 cm wide and 4.3 cm in height and may be incorporated with the modules.

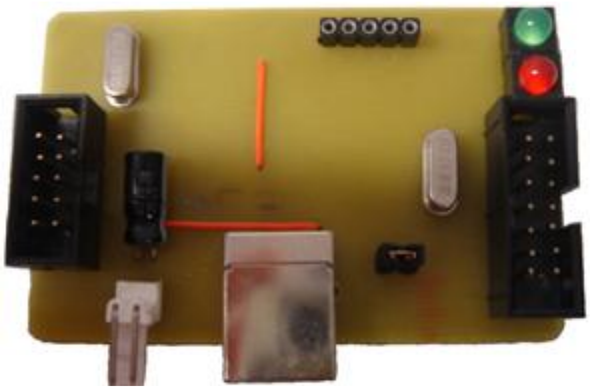

Fig. 5 Central controller.

Is the central controller that is aware of all modules connected to the bus, so was decided to incorporate on this the RGB light sensor TCS230 that makes the color correction of the entire display. The RGB light sensor is connected to the central controller through the expansion connector, and can be installed near or at the modules in order to determine the intensity of ambient light that focuses on them.

Despite the central controller only include communication with the computer via USB, it is possible add other communication modules using the expansion connector. This connector is prepared for the standard RS-232 allowing the connection to a wireless module that uses the GPRS mobile network, enabling communication over long distances.

VI. Software

A. LED module microcontroller firmware

The dsPIC30F6012A firmware, Fig. 6, begins by making the necessary initializations, such as:

- Reading of the module identifier;
- Configuration of the SPI modules for TLC5944 and MAX7301;
- Starting the PWM module to generate the clock signal GSCLK;
- Configuration of timer3 to be incremented in each GSCLK cycle and generate interrupt every 4096 cycles;
- Startup of the CAN module and the LED controllers;
- Load the images saved in the EEPROM to RAM;

Each module has an identifier allowing the distinction of the messages that correspond to each one, also allows being located on the row and column in which they are located on the display. This identifier is selected by DIP-switches when installing the module and its value is read during the initialization.

In the CAN module initialization, this is set to the maximum baud rate (1 Mbps), use of extended identifiers (29 bits), and the filters set to receive only the messages destined for the identifier of each module or global messages intended to all modules.

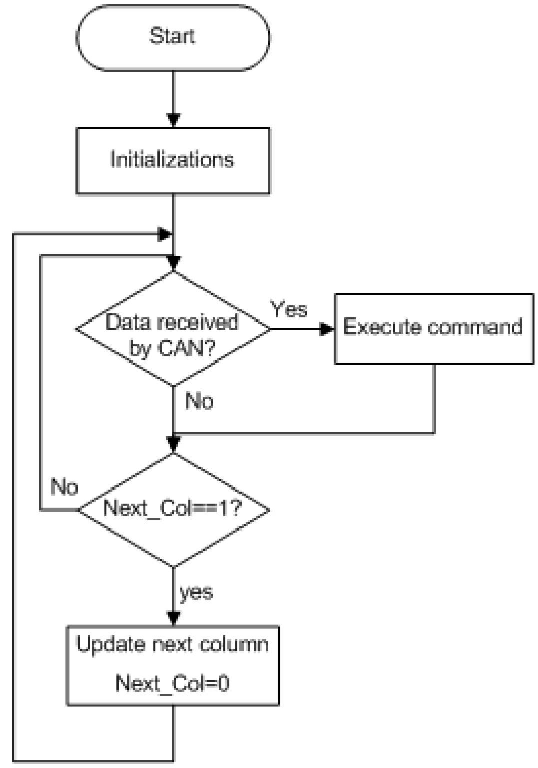

Fig. 6 Flow chart of the LED module firmware.

At this stage, are also loaded to the respective variables in RAM the images that were stored in EEPROM, due to this being a non-volatile memory.

After initialization, the program enters to main loop where it begins by checking if there are data received via CAN bus. If there are, is executed the command corresponding to the bits of the identifier of the received message. Can be received 5 different commands:

- Load image;
- Change brightness;
- Store in EEPROM;
- Save image frame;
- Obtain identifier;

It is then checked if it is possible to advance to the next column of the matrix, and if so, updates the data of the LEDs referring to this column.

This main loop is repeated infinitely.

Features

Each module can store 10 images, which allows change the image or make an animation without having to resend each picture.

The application of this work is the integration in road signs and not the video display, so it is unnecessary large color resolution, thereby reducing the time to send the images. As the CAN protocol allows sending only 8 bytes of data at a time, was chosen use 4 bits per color, resulting in a total of

4096 colors. This allows to simultaneously sending the data for a complete line of one of the colors of an image.

Despite the EEPROM only have 4 kB of memory, the use of 4 bits per color also makes it possible to save all 10 images, because they occupy 10×384 bytes = 3840 bytes.

As described above, was used 4-bit resolution for each color, but the controller allows up to 12 bits of resolution. So it was necessary to create a conversion table in which each of the 16 values corresponds to a value between 0 and 4095. But the relationship between luminance and brightness is not linear, and although they are often used interchangeably, luminance and brightness [15] are not synonymous.

Luminance refers to the light emitted, projected per unit area and measured in cd/m² (candela per square meter).

Brightness refers to the perception of luminance attributed by the human eye.

To correct the nonlinear relationship between luminance and brightness is used gamma correction, and is given by (1) [15].

$$\text{luminance}_{\text{corrected}} = \text{luminance}^{\gamma} \tag{1}$$

For cathode ray tube screens are generally used a γ of 2.2 [8]. In this case γ is given by (2).

$$4095 = 15^{\gamma} \iff \gamma = \log_{15} 4095 = 3{,}07 \tag{2}$$

The conversion obtained from the gamma correction is represented graphically in Fig. 7.

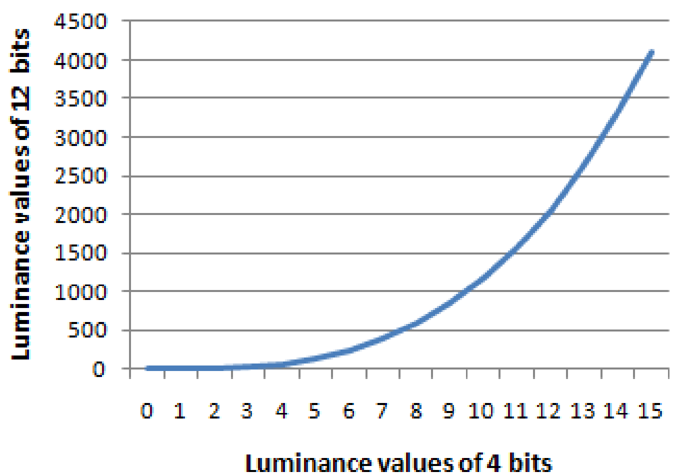

Fig. 7 Relationship between the luminance values with gamma correction.

As noted above, meant to be a refresh rate above 60 Hz so that the viewer will not notice flicker in the display. From Fig. 8 it is determined that for this to be possible it is necessary an FFT greater than 3.9 MHz, therefore is chosen 5 MHz because it is the frequency that the microcontroller of the module allows. Thus is obtained a frequency $F_{Img} = F_{refresh} \approx 76$ Hz.

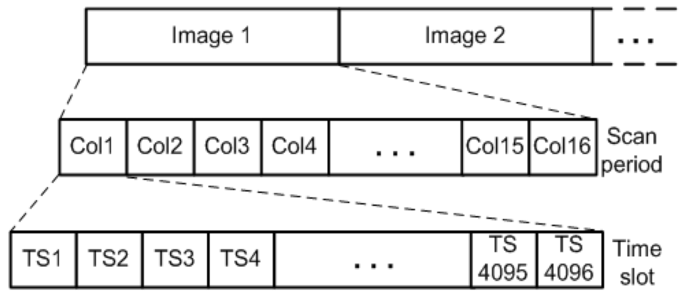

Fig. 8 Temporal hierarchy of the module LED.

B. Central controller firmware

The program, represented in Fig. 9, initially performs the necessary initializations, including:

- Setting the timers and their interruptions;
- Configuring the SPI module;
- Starting the USB module;
- Configuration of the CAN module of MCP2515;
- Collection of identifiers of all active modules in the CAN bus;

It is necessary to provide from the computer to the central controller a large amount of data that make up the images. Hence the USB module was configured for bulk transfers and maximum allowed speed limit, which is full speed. With this type of transfer ensures too that data is received without errors.

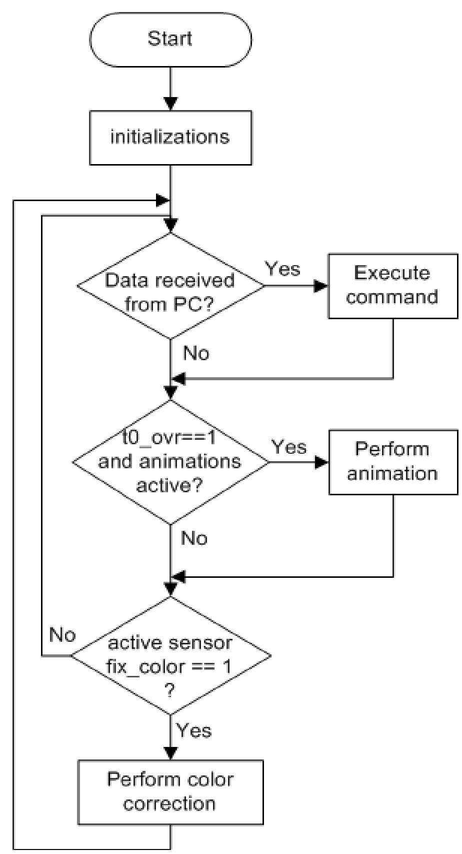

Fig. 9 Flow chart of the central controller firmware.

In the CAN module initialization, this is set to the maximum baud rate (1 Mbps), use of extended identifiers (29 bits), and filters set for receipt of all valid messages.

For the central controller can send data to all modules connected to the CAN bus, it is necessary to know their identifiers, and so it is done at this stage a takeover of these identifiers. Thus it is also possible send to the computer the number of modules and their positions on the display.

Then the program enters in the main loop where it begins by checking whether there are data received from the computer. If there are, is executed the command corresponding to the received message. Can be received 7 different commands:

- Save image frame;
- Load image/animation;
- Obtain identifier;
- Store in EEPROM;
- Change brightness;
- Enable/disable the light sensor;
- Test command;

The next step of the program is to verify that the animations are active and simultaneously occurred a timer0 interrupt. If the condition is true it runs the function that handles the animations.

Finally, if the light sensor is active and simultaneously has reached the moment of time that should be a new color correction, is performed the corresponding function.

This main loop is repeated infinitely.

C. Software

The program that runs on the computer to allow control and monitoring the display by the user was developed in C Sharp (C#). It consists of two important windows, the main window and the editing window. In the main window is made the control of the display, the monitoring, the transmission of images, the configuration of the animations, and the adjust of brightness or color correction.

The editing window has been developed from the icon editor *VariIcons* available at *sourceforge.net*. From this editor was used the graphical interface and changed its programming in accordance with the desired needs, including the replacement of functions that make the import and processing of icons for functions corresponding to bitmap and jpeg images.

This window has a useful collection of drawing tools in the toolbox. These tools can be used to create the images, add alphanumeric messages, make corrections in color and contrast, rotate, or add a variety of forms to the images before sending them to the display.

Another important factor is the ability to resize the images to be displayed in accordance with the current resolution of the display.

All these basic tools are available in a single program, it is not necessary the use of a separate image-editing program, and also allows simultaneously the control of display because the main window stays always active.

The software makes the communication with the central controller via USB, but easily allows the addition of other communication protocols by simply change the functions corresponding of USB to functions corresponding to the intended communication.

The requirements for the program are:

- Windows XP, Windows Vista;
- .NET Framework 1.1;
- 64 MB RAM;
- 1 MB of disk space;

The program is user friendly and intuitive, informing the user of the settings required when sending images to the display. Another important feature is the graphical representation of the current configuration of the display, allowing a simple check if all installed modules were detected or if there has been any failure.

VII. Results

To proceed the test of displayed images on the display was initially tested with only one LED module to evaluate the performance with 16x16 images.

The result with some sample images are shown in Fig. 10, but with this test is not possible to evaluate the quality of the images because the current resolution of the display is low.

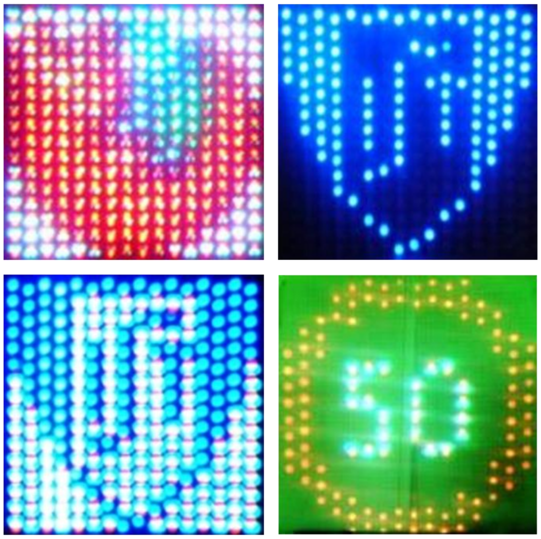

Fig. 10 Samples of 16x16 images on the display.

After the proper functioning of the LED module, the next step was to add horizontally to display a second module, making sure that their detection is done automatically. With this new configuration the display allows to receive 32x16 images dividing them by each of the respective modules.

As shown by the examples of displayed images in Fig. 11, does not distinguish the line between the modules, which shows that the partition of the image was successfully made.

Fig. 11 Examples of 32x16 images on the display.

When the images are close-ups the LEDs appear as independent points, as seen in the example images shown.

The minimum distance from the display where these LED's are mixed into a single color is known as the color compound distance, and can be calculated by the distance between pixels multiplied by 500 [4]. For this display the color compound distance is 8.2 m. This is also sometimes mistakenly called minimum viewing distance.

The minimum viewing distance is the distance below which the image is seen as a set of individual pixels, and for discrete LED displays is calculated by the distance between pixels multiplied by 1000. For this display a viewing distance above 16 m allows to see a smooth image.

The specifications of the developed display are in summary in Table 3, allowing the comparison with the specifications of commercial displays such as shown previously in the state of the art.

Table 3 Developed display features.

Pixel configuration	1R, 1G, 1B
Pixels pitch [mm]	16,4
Module size [mm]	262x 262x30
Module resolution [pixel]	16x16
Module quantities in a cabinet	4x4
Pixel density [pixel/m^2]	3844
Brightness [cd/ m^2]	≥ 2200
Brightness adjusted	64 grade
View angle	30º
Best viewing distance [m]	> 16
Communication distance [m]	CAN bus: 40
Communication interface	USB
LED driving method	Constant current
Bits per color	4
Refresh frequency [Hz]	76
Screen lifetime [hours]	≥ 50 000
Power supply	DC: 5 V AC: 220 V 50 Hz
Power consumption [W/m^2]	Max: 96
Other features	• Modular architecture; • Non volatile memory; • RGB light sensor for color correction; • According to EN 12966;

The features that stick out among the displays presented as an example are the fact that this display has a much lower consumption, although the brightness also is lower. Another factor that distinguishes it is the using of the RGB sensor for color correction.

VIII. Conclusions

This document was presented a matrix display of LEDs to show both alphanumeric characters as color images. The system consists of a tricolor matrix with a circuit to interface with a computer. It also includes a program that runs on the computer to control the information to be displayed.

The constitution in modules allows a higher resolution display by association of identical modules. This feature also facilitates the transport and quick repair in case of failure by simply replacing the malfunction module.

The design of the system was taking into account the definitions of EN 12966 allowing the incorporation into road signs, thus expanding the range of possible applications.

The results were promising, and while here were described the prototyping of the system, it is expected the development of the product for general marketing.

IX. Future work

As future project aims to implement the GPRS wireless module for that the display can be controlled remotely, since the integration is not complete in this work.

Can also be made many other improvements, including setting up the verification of failures in the LED array, since the controllers already include this functionality.

As the brightness obtained is lower than the commercial displays, the maximum current in the LEDs must be increased and must be added systems for monitoring of LEDs, which, despite reducing the useful life of LEDs is necessary to increase the brightness.

For the prototype developed were used two separate boards for the control of the matrix, but eventually intends to integrate the microprocessor on the board of LED drivers.

Besides all this is also needed to build the support structure of the display that suits the conditions for installation in the external environment.

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