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Abstract. Nowadays, the devices have the role to be user-friendly with the touch interfaces. In this paper it is presented an interactive touching device fully supported in LED technology. This is achieved through the use of an array of LEDs where each one works as a light emitter and as a sensor. The implementation uses a microcontroller to control the LED operation. Also it is proposed a new LED unit matrix configuration that avoids the use of an external light source to detect any touch. This new architecture only needs two microcontroller input/output to each row plus column which provides a user-friendly interactive contactless interface. Also it is explained how to aggregate these unit modules into a bigger LED display panel, reducing implementation costs.

Keywords: Light Emitting Diode, LED Matrix, Bidirectional LED, Air Touch, Remote Touch, Multi Touch, Interactive LED, Touch Sensor, Display Devices.

1 Introduction

Light Emitting Diodes, or LEDs, are nowadays a very common source of light due to their higher energy efficiency, and easy dimming light control through standard Pulse With Modulation (PWM). In addition, this device can also be used as a photosensor [1], which can operate as a light emitter in one phase, and as a light sensor in other phase, all without hardware modifications. This coordinated operation can transform a large LED display, like advertising panels or queuing information panels, into a bidirectional interface with, basically, the same hardware. Moreover, the LED sensing capability can also be explored as a wireless two-way communication port [1].

Considering a matrix of LEDs, by quickly switching them between forward-biased (light-emitting) and reverse-biased (light-sensing) modes, it is possible to create dynamic images while measuring the lighting level, at the same time. In [2], some techniques to sense a touch finger with an LED matrix are presented, which can measure the reflected light through finger proximity. The operation can be managed by a master controller which controls each desired pixel intensity, while a slave module is dedicated to forward and reverse bias the LEDs.

In this paper, techniques will be studied with the objective to implement a display that can produce an image, while measuring the ambient environment. A master controller, using a dedicated protocol, controls its operation but at the same time transform it into an interactive contactless input interface. For instance, each frame defines all intensity to each pixel followed by the setup of one of three modes, only light emission, sense, or at the same time sense and light emission.

Each module only completes the cycle when all LEDs provide the desired operation requested by master controller. For the light emission stage, the microcontroller (μC) can provide at the same time the complete LED row, and finishes the cycle when all rows are completed. In case of sensing only the ambient lighting level, the microcontroller read all columns in the row at the same time, and after finishes all rows, send each value of each to the master controller, and wait for other cycle mode. In the sense and light emission mode, all LED in the same row in odd columns are emitting. In the neighbor row, sensing light in even-numbered columns are accomplished. The cycle is completed when all pixels generated a proper value of intensity light, received the feedback light of each one and sent the feedback values to the master controller.

With this methods, the touch display implementation have low cost and low complexity hardware. It can also be used to sense multiple lasers with different wavelengths which are pointed by distinct users at the same time allowing the differentiation of the remote touch of each user, being similar to [3] in remote touch parameter.

2 Contribution to Collective Awareness Systems

Nowadays, the emergence of collective awareness systems is pushing the performance of end user interactive objects. The support framework based in interconnected objects and things (IoT) is the bridge that combines technologies and components from micro-systems (miniaturized electric, mechanical, optical and fluid devices) with knowledge, technology and functionality from several areas of research. In other words, the devices have to have embedded capacity to integrate a system, to be capable to interact dynamically having into account proprieties like lower resources and multi-functionality.

This paper will focus on the functionality of the smart touching devices for a wide range of dynamic and creative interactive applications, combining low cost and, in some cases, the usage of the same hardware with only a software update.

3 Related Works

Normally, the touch screens have separated technologies for imaging and touching functionality, [4]. The latter is can be embedded in the display using capacitive or resistive membranes. Alternatively, a lateral infrared strip can be used [5] or standard external cameras with sophisticated image recognition can detect the fingertips.

The novelty in this paper is the possibility to transform a standard LED display into a multi-touch, contactless touch and distance touch (e.g., using lasers) with almost no additional costs beyond the display itself, while maintaining a low system complexity, since it needs software modifications and only a few ones in hardware.

4 Using an LED as an Emitting/Sensing Light Device

Light emitting diodes have a similar exponential current-voltage curve when compared with a normal diode. The main property of an LED is the emission of light with a certain wavelength profile. Interestingly, this device also reacts to incoming photons with the same wavelength, enabling the use of the LED to measure the intensity of that radiation. One of the techniques is to measure a tinny voltage across the LED that is proportional to the intensity radiation. The other one, used in this paper, is based on the behavior of reverse biased pn junction under radiation conditions. When reverse biased, the radiation charges the LED intrinsic capacitor inverse to the radiation, this means that the equivalent capacitor is smaller in high light conditions, and bigger in low light conditions.

To measure the charge in the capacitor after the inverse biased phase, it is important that the measuring current is small. One method mentioned in [1] is using a digital comparison input, counting from the moment that the I/O_1 changes to High-impedance until a threshold that the microcontroller assumes a LOW value. That count is related to the incoming light intensity on the LED.

Figure 1 shows how to drive a simple LED with two input/output of the microcontroller to enable the switching between emitting and sensing light.

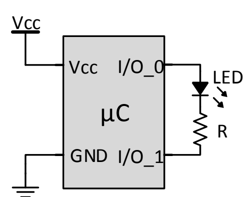

Fig. 1. Schematic of a bidirectional LED.

To understanding the full behavior of LED when reverse biased, the charge reading process is equivalent to a Resistor-Capacitor (RC) circuit, that the R is the input impedance of the microcontroller, and C the intrinsic capacitor of the LED, and including a parallel of a current source, equivalent to a small leakage current. The electric equivalent in each state is shown in Fig. 2, and in c) shows a resistor that can be added (in grey) to have shorter time constant. This technique has the same power consumption, because the main contribution comes from the forward biasing phase.

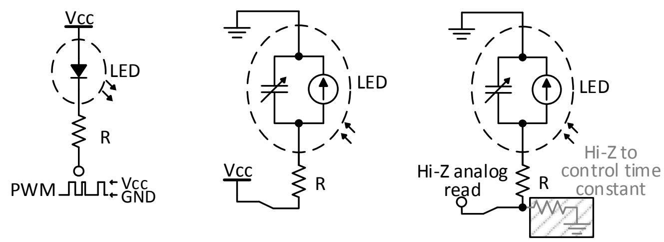

Fig. 2. Different stages of biasing LED with equivalent electric behavior. a) as light emitting variable. b) reverse bias to charge capacitor. c) read received light.

Figures 2 a) to c) show the sequence of emitting and measuring light steps. The case in Fig. 2 b) is needed to charge the LED junction that is related with the incident light.

The operation can be analyzed as a first order RC circuit with a time constant given by,

$$\tau = RC, \qquad (1)$$

where R is the equivalent of the current limiting resistor in series with the parallel of input impedance of microcontroller and the pull-down high-impedance resistor (if needed) to allow the adjustment of R, and consecutively τ due to equation (1), and C the intrinsic LED capacitance.

The implementation using an RGB LED has to enter, firstly, into a pre-calibration step to adjust the sensitivity in relation to each color. The lenses in some types of LEDs are used to mix colors, which introduce an additional degradation factor to sense light. The pre-calibration step will adapt the firmware of the microcontroller to adjust the sensing sensitivity when red, green or blue lights are within the detection range, or the combination of them.

5 Bidirectional LED Array for an Interactive Interface

When the goal is to have the largest possible number of LEDs with just one microcontroller, a non-inverter driver can be used drive at the same time an entire row. This is needed because the microcontroller outputs are not capable to drive all LEDs in a row. However, to allow emitting and sensing light at the same instant, only two rows are used, while the others must be in high-impedance to not interfere in the measurements, meaning that the driver can be a tri-state type (Fig. 3).

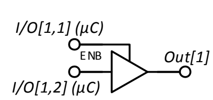

Fig. 3. Schematic of driver for multiple LED array (Tri-State).

An issue to take into account is the refresh rate of the total LED matrix, which has to be higher than 100 Hz to be undetectable by the human eye. On lower light conditions (bigger time constant), it should be defined a fixed maximum time to each operation and if the time constant is still too high a proper resistance value has be selected to obtain shorter discharges (grey in Fig.2. c)). In higher light conditions, the precision depends on the comparison rate of the microcontroller.

The matrix in Fig. 4 is a model that can be configured depending on inputs/outputs available on microcontroller, wherein two outputs are used for each row and an I/O for each column. The time for each cycle goes from the beginning of the frame received from master controller, Fig. 5, until light emission mode, receive mode, or both be completely performed for each LED.

For the first case, light emission mode, the controller output that controls the row through the tri-state driver puts the logical HIGH value, while the outputs directly connected to current limiting resistors generate a PWM with the desired Duty-Cycle for a certain time. The cycle ends when all rows are covered.

In the case that only is needed to measure the ambient light, the process is similar, but now it is necessary to impose the LOW value in the row, and HIGH value in each column to charge the intrinsic capacitor. Only after, the measurement of the charge accumulated in the junction of each LED in that row is taken. Note that the measuring light occurs from all LEDs in the row at the same time, and when some finishes, the microcontroller waits a programmed guard time. The cycle finishes when all LEDs are measured and that values are sent to a master controller.

When the microcontroller enters into a emit and read modes, first it has send the frame containing all PWM values for each LED, and after that, the first row is taken HIGH, while the odd columns are generating PWM. The sensing is made in the LED in the diagonal immediately at lower right position, while the other rows are in high-impedance state. After that, the other rows should have the same behavior, until the last one does not have any LED around in a sensing state, because that row is emitting (odd columns), and the first one is sensing (even-numbered columns)., This is made keeping in mind that the LED matrix can be surrounded by another one, in large display structure. Yet it is necessary to maintain the same behavior, but now emitting in even-numbered columns and sensing in odd columns. Finally, each value sensed should be sent to a master controller.

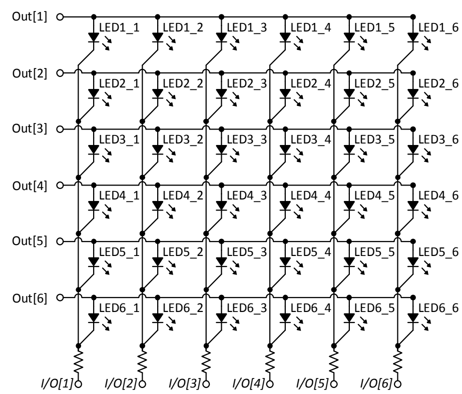

Fig. 4. Example model of an LED matrix.

Figure 5 shows how to connect multiple modules, creating an interactive display controlled by a master controller or a simple computer, all this through a serial communication link.

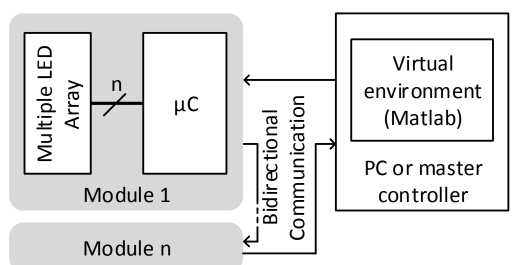

Fig. 5. Interconnection between the LED and master controller through a serial communication.

6 Experimental Evaluation of the Proposed Matrix

To validate the proposed LED matrix, a single array of six basic red LEDs of three millimeters were designed and implemented. The green LED also was tested, and have basically the same behavior.

The microcontroller used was the ATmega328, from Atmel. Figure 6 shows the schematic assembly of the LED array prototype, in which 'Out_1' is driven by a non-inverter similar to Fig. 3, but without ENABLE since an Hi-Z state is not need for a one row configuration.

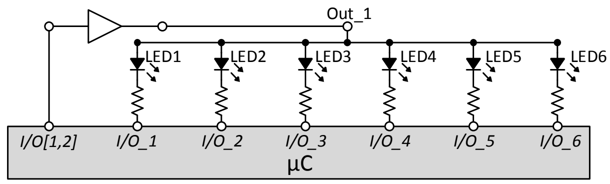

Fig. 6. LED array setup with MCU.

The setup used is similar to Fig. 5, but having just one module. A serial communication to a virtual environment, created in Matlab, was used to demonstrate the user interactivity.

Remember that the microcontroller only finishes the phase of sensing when all LEDs reaches the threshold voltage, meaning than if one LED arrives at the threshold value the microcontroller waits until the last one, allowing a measured with an oscilloscope than the voltage across the LED measured drops much faster because the ten megohm input impedance.

To determine the time constant, measurements where performed with a digital oscilloscope. Figure 7 shows the measurement results of each phase.

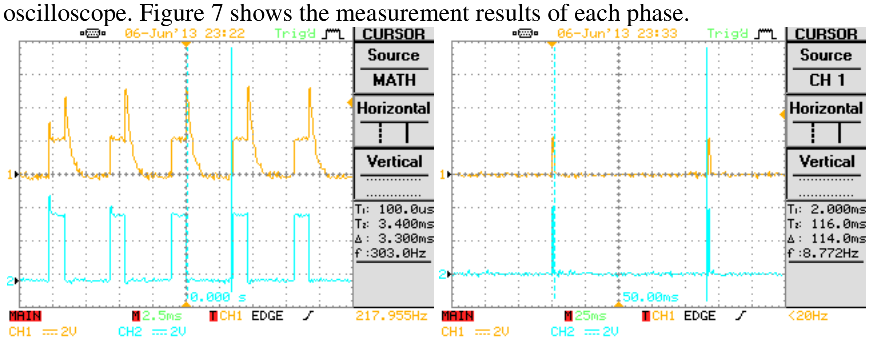

Fig. 7. Measure of reading time of received light Δ (CH1 cathode of LED, CH2: anode of LED). a) case with high light conditions b) case with low light conditions.

In Fig. 7 a), the time constant is the time that the voltage across LED drops from Vcc to $Vcc \cdot e^{-1}$, but the threshold voltage of microcontroller is around $2V$.

Through the proportionality rule,

$$\frac{\Delta}{\tau} \leftrightarrow \frac{Vcc - 2}{Vcc - Vcc \cdot e^{-1}},$$

which Δ is the value obtained in each measure of Fig. 7, and time constant τ is 3.5ms and 120ms for high and low light conditions, respectively.

Since the input impedance of microcontroller is in the range of some megohm, these experimental results show that the capacitor is in the range of a few picofarad and near nanofarad in high and low light conditions, respectively. We cannot change this intrinsic values, but adjusting a proper resistor like in Fig. 2 c) in grey, the time constant can be manipulated to boost higher refresh rates. However, for lower refresh times, a faster microcontroller may be needed. Note that these values depends on LED, and microcontroller features.

A real time interactive interface was created to view the values determined by the microcontroller from which a synthetized a musical tone proportional to the proximity distance of a finger, was generated. For example, Fig. 8 b) shows a finger proximity in the third LED.

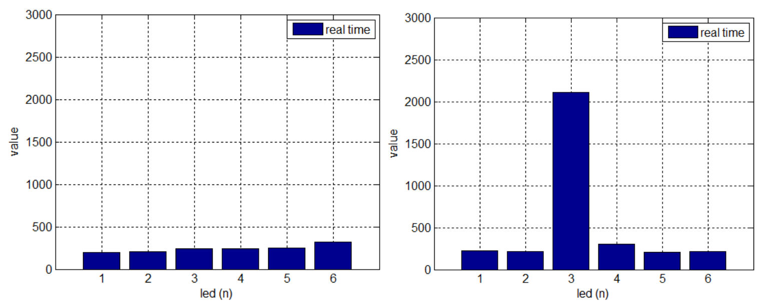

Fig. 8. Measure ambient light (lower value means higher light). a) without light obstruction (ground level). b) with a finger on third LED.

The Matlab demo application consists of a piano synthesizer, in which each LED corresponds to a musical tone, and giving an indication to the user of the tone touched by changing the corresponding LED light intensity (amplitude of the sound level is proportional to the light intensity).

7 Conclusion

The techniques presented in this paper allows the implementation of contactless LED based matrix smart interactive interface that can operate in a robust way for each application. The information processing may be performed by a computer or a master controller, which enables the setup of large area displays. In each module, each slave microcontroller can be replaced by a System on Chip (SoC) capable of producing the desired outputs for driving each LED, read ambient light and transm. In smaller applications, only one microcontroller can be used to generate their own interactivity.

With this architecture of touch displays, the global cost is almost the same as a normal LED matrix display, with practically the same complexity and a software modification, not forgetting that the consumption remains practically equal due to the small intrinsic capacitors that have to be charged and uncharged to measure light.

Through this system, we expect a touch interface as the important component in these days to provide the high quality of services to users for applying to a variety of applications easily and giving the intuitive interface.

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