DEVELOPMENT OF A MICROCONTROLED IRRADIATION SYSTEM BASED ON LIGHT-EMITTING DIODES (LEDs) MATRIXES FOR PHOTOTHERAPY APPLICATIONS

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Abstract: Light Emitting Diodes (LED´s) are semiconductor devices that explore the concepts of physics of semiconductor materials and the theory of bands to efficiently convert electrical energy into electromagnetic radiation. Currently the LED´s are devices widely employed in electronics, and their applications can range from simple lighting design, light communication apparatus and sensors to the development of lighting systems for medical purpose. We can mention as an example of medical purposes, devices based on LED´s used in light-mediated therapies such as Phototherapy. This paper describes a prototype of a microcontrolled irradiation system based on LED´s matrix to be used in the treatment of skin healing, more specifically in the treatment of oral mucositis..

Keywords: *LEDs, phototherapy, microcontrolled systems.*

1. INTRODUCTION

With the rise of the LED technology, it is common to see it being used in many different places, for example, in watch displays, home appliances or traffic lights. It is becoming more popular in the lighting market thanks to its low power consumption, long lifetime and low maintenance [1]. Additionally, LED´s can produce light of different colors and intensity, covering the entire light spectrum, including red, orange, yellow, green, blue and white. Besides, this light source consumes 50% less energy than incandescent bulbs.

In addition, LED´s have been showing efficiency in other areas, such as medicine, dentistry, physiotherapy, architecture and agriculture. This is due to the fact that we can easily control the properties of LED´s light, such as spectral distribution, polarization, intensity and temperature, opening a range of applications for these devices. In medical field the LED´s can be used in the treatment of premalignant and malignant lesions, rejuvenation and acne treatment, hair loss, skin lesions and healing of chronic and acute wounds [2-3].

In this context studies to quantify the radiation at specific wavelengths have collaborated with studies that deal with the interaction of certain electromagnetic waves (in this case, luminous) with biological systems. Light source characterization studies, as a function of light emission wavelength and luminous intensity, are needed. The application time of this light is also an important factor in the treatment of different diseases. In particular, the use of LED´s as light source for therapeutic purposes has been the focus of recent studies in the prevention and treatment of chemotherapy-induced oral mucositis in pediatric patients [4-5].

The aim of the present work is to develop of a microcontrolled system that is responsible for the temporal control of light doses for therapeutic purposes. The microcontrollers are simple programmable devices with great potential for generic applications that normally do not require other external integrated circuits for its operation, except in more elaborate applications, since they already have several internal integrated peripherals. This contributes to the reduction of costs and size of the project [6].

2. PHOTOTHERAPY

Phototherapy, also called Photobiomodulation is a kind of treatment which involves the application of light over biological tissue to elicit a biomodulative effect within that tissue. The light source used can be derived from a LASER (coherent, monochromatic light, stimulated emission) or LED (non-coherent, monochromatic light, spontaneous emission) system. Studies showed that the coherence of light has no importance in clinical effects [7], and there is currently little doubt that light emitted by LED´s is so effective in biomodulation process within living tissue and present good therapeutic results if used correctly. Nowadays the Phototherapy is gaining great acceptance in several medical area such as physiotherapy, dentistry, acupuncture and dermatology. One of the main uses of the LED´s is in the light-induced wound healing process by local application of LED´s light [8]. It is important to mention that for every situation there is a specific wavelength to be used to produce a desired effect [9].

In the skin, the red light originated from a LED´ system has an anti-inflammatory and healing action, because it helps cell multiplication. When the skin receives light with wavelengths greater than 800nm, tissue heating occurs due to energy absorption by water molecules. However, decreasing the light wavelength, the penetration in the skin decreases, because the absorption of organic compounds and sharp light scattering. Figure 1 shows the relationship between the wavelength and the light penetration in the skin. The literature claims that the region between 600nm and 800nm is ideal for the application of Phototherapy [1]. In particular, several studies indicate that some wavelengths provide a better biological response, among which, 620, 680, 760 and 820 nm could be best suited due to more intense absorption [10].

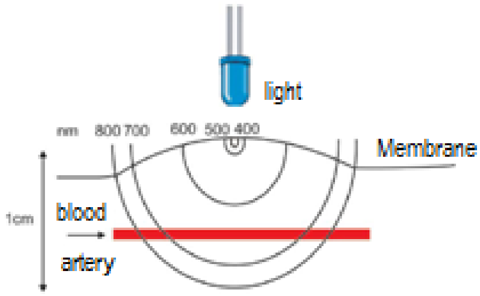

Figure 1. Light penetration into the skin as a function of wavelength [1].

2.1. Physical parameters in Phototherapy

Complete report of the physical parameters used and light exposure conditions in Phototherapy is essential to understand interaction mechanisms and allowed the replication of the obtained results. These parameters include power density, optical power, irradiated area, time of light exposure and dose of energy. The definition of power density (PD) is the optical power given in Watts (W) divided by the irradiated area in square centimeters (cm^2). The dose of energy (DE), expressed in Joules per square centimeter (J/cm^2) is obtained by multiplying the PD by the time of light exposure, in seconds [11].

$$DE = (P \; x \; t)/A \qquad (1)$$

where:

P = optical power (W);

A = irradiated area (cm^2);

t = exposure time (s);

The use of correct dose of energy or fluency is very important to obtain good results and to permit the replication of these results in Phototherapy. Very high doses can cause tissue damage and very low doses may cause no effects in the tissues. Very high doses can cause, for example, thermal damage to biological tissues, and can harm the patient [11]. We can see the relation between dose of energy to be applied and desired effect in Table 1.

Table 1. Relation between dose and desired effect in biological tissues [1].

Desired effect	**Dose (J/cm^2)**
Anti-inflammatory	1 to 3
Circulatory	1 to 3
Pain relief	2 to 4
Regenerative	3 to 6

According to the table, we can observe that for regenerative purposes it is recommended to apply a dose between 3 and 6 J/cm^2. For application of Phototherapy for skin healing, this amount of energy is ideal.

3. Microcontrollers

We can define the microcontrollers as being a small electronic component provided with programmable intelligence. The whole logical operation is structured in the form of a program and recorded within the component [12].

The microcontrollers consist of an encapsulated silicon wafer with all the necessary components to control a process. This means that they are internally provided of program memories and data, parallel input and output ports, timers, counters and serial communication.

The PIC microcontrollers feature a machine architecture type Havard, which has two different buses: one for data (8 bit) and another for program (14 bits). So, while one instruction is being executed another is fetched from memory, allowing flexibility to the processing [13].

In the present work, we used the PIC 16F877A microcontroller from Microchip. This 8-bit microcontroller is easily programmed with only 35 instructions, it contains between 40 pins that can be enabled as input or output signals that can be analog or digital. Among other features, it has EEPROM memory, capture/compare/PWM module, A/D converter and serial transmission USART [14]. The pinout of this microcontroller is presented in Figure 2, where it can be observed through the pins nomenclature, that many of them have more than one function, which will depend on the internal peripherals configured and the application itself.

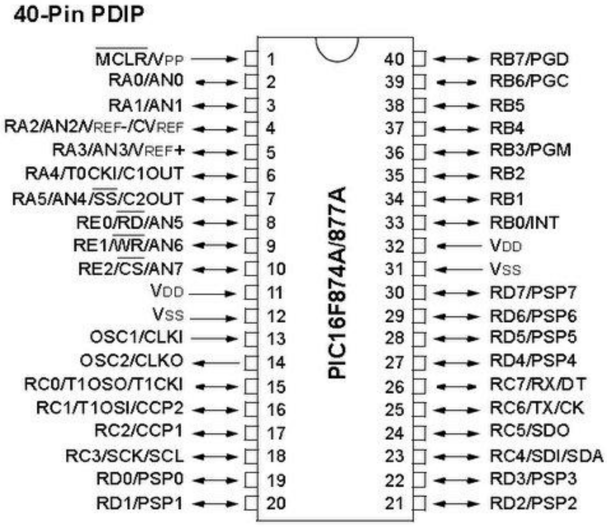

Figure 2.PIC16F877A microcontroller pinouts.

The PIC also has three features of timers with their own characteristics. In this work, we used the Timer0 by interrupting its counter TMR0. This interruption is commonly used for timing [12].

Two other interesting pins are the RB0, which can be configured to act as signal input and activate the external interruption and the pin 1 of the PIC/MCLR, which works as external reset, is activated at logical level 0 [12].

In the first part of this work, the construction of a prototype consisting of 9 LED´s, of 5 mm, arranged in regular and symmetrical shape forming a 3x3 matrix was proposed. This matrix was powered by a 5V source for future use with the microcontroller. The three matrixes, presented in Figure 3, were made with LED´s of different manufacturers, but all red in color.

Figure 3. Three different matrixes forming a 3x3 LED matrix.

Aided by the OSA (Optical Spectrum Analyzer) it was possible to measure the wavelength of the three different LED´s used in this prototype. The optical power of the matrixes was measured with the aid of a power meter (Coherent). Through this power values, the time of light exposure to achieve the dose of energy required to cause the regenerative effect in the skin was calculated. This calculation was done using Equation 1.

Analyzing the three matrixes, we can conclude that only with one of them, a considerable time for Phototherapy application was obtained. So, for the development of the first microcontrolled system only one matrix was used.

For greater design flexibility, a microcontrolled device with varying times, was proposed in this work. Thus, the study of LED´s matrixes could have continuity and improvements should be made, for example, changing the type of LED´s or the geometry of the matrix lightning.

As stated before, it was used the PIC 16F877A microcontroller. It will control the time that the matrix is connected, according to the time selected by the user. To select the time, two buttons will be used: the increment and decrement. The start and reset buttons are also implemented. The reading will be done by a bar of LED's indicators. For timing, the interruption of Timer0 will be made.

The Timer0 is an 8-bit register whose value lies at the register TMR0. Its increment is done from the RA4 pin when used for external event count or each machine cycle for timing. To define what kind of increment will be done simply modify the bit TOCS of the register (OPTION_REG). When the bit is recorded in 0, its increment is done in every machine cycle and when it is in 1, it is made by transition in RA4 pin, which is an external clock pulse [12].

It is also necessary to set it as the counting speed. Using the OPTION_REG register, it is possible to set the value of prescaler, which determines the division count, i.e., how many machine cycles (timer) or external pulses (when external counter) will happen for the register of counting time TMR0 to be incremented. The value of the prescaler of TMR0 varies from 2 to 256, i.e., with values of 2^n (varying the value of n between 1 and 8). When the transshipment of TMR0 occurs, that means that its value changes from 255 to 0, a flag at the register INTCON will be set (the T0IF bit will change from 0 to 1), indicating that there was an interruption. To calculate the frequency with which the TMR0 interruptions will occur, the following formula shall be used:

$$F_{int} = \frac{CLOCK}{PRESCALER\ x\ (256 - TMR0)K} \quad (2)$$

where:

-CLOCK is the frequency value of the used clock. In the case of internal oscillation is Fosc/4;

-PRESCALER is the division factor of the clock;

-TMR0 is the initial value of TMR0.

-K is a multiple if the values of TMR0 and PRESCALER are larger than 256.

Based on the physical principle that time is the inverse of frequency, we have:

$$T = \frac{1}{F_{int}} \quad (3)$$

where T is the exposure time of the LED´s.

The algorithm of the microcontroller was done in assembly language using the MPLAB (Microchip). For simulation, the electrical circuit in the ISIS 7 software was done, also known as PROTEUS. For implementation of the printed circuit board (PCI) the EAGLE software was used for the design of the plate and the EAGLE 3D for the visualization of the plate before the physical implementation of the same.

To power the PIC 16F877A, a 12V alkaline battery and a plastic holder were used. To adjust the voltage a LM7805, that will supply the 5V needed for the proper functioning of the PIC, was used. For the microcontroller clock frequency a 4 MHz crystal was used.

In the user interface, in addition to the already mentioned LED bar, 4 buttons with four pins each were used. The 330Ω and 100kΩ resistors were used for protection of the LED´s bars and buttons, respectively.

4. RESULTAS AND DISCUSSION

With the three LED´s matrixes assembled and fed properly, it was possible to measure the optical power in the maximum wavelength using the power meter and calculate the exposure time, according to Equation 1. It was considered a dose of 6 J/cm^2, regarding the regenerative effect of the skin (Table 1).

The area illuminated by the matrixes considered for calculation is the area of the light beam of the LED´s at a distance of approximately 2 cm from the matrix ($2{,}25\ cm^2$).

In table 2, it can be seen that matrix 1 has the highest luminous power, and the shortest exposure time for a dose of the 6 J/cm², justifying the choice of this matrix as the best suited for Phototherapy application.

Table 2. Power and irradiation time of LED arrays.

Array	Wavelength (nm)	Power (mW)	Time
1	632	23.58	9' 32''
2	633.8	6.84	32' 53''
3	(not informed)	0.4401	8h 31' 14''

Analyzing the implementation time of this matrix, it was concluded that the optimal time for implementation is up to 10 minutes. Therefore, the final device was designed for counting the time from 1 to 10 minutes, ranging from 1 and 1 minute, depending on what was selected by the user. Figure 4 shows the electrical system made in PROTEUS of the second microcontrolled device. The LED´s 1 to 10 are related to the LED´s that will show the time to the user.

The INC and DEC buttons are responsible for controlling the LED´s bar, which will show to the user the length of time the matrix will be switched on when the START button is clicked. The RESET button is on the pin of the PIC that has the function to reset the program. This will cause the matrix to be switched off automatically when this button is pressed.

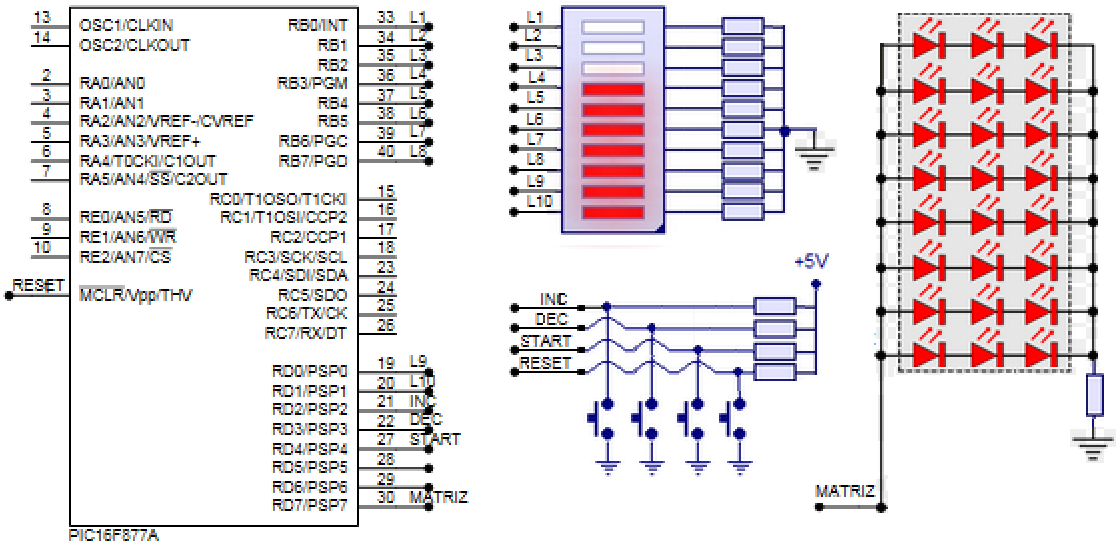

Figure 4. Electrical diagram of the second microcontroller system for the matrix of LED's.

Figure 5 shows the flowchart of the program. The algorithm tests whether the buttons INC, DEC and START were pressed and then make the correct decision. The RESET button is not tested in the program because it is a button with a specific PIN of the microcontroller, as stated before.

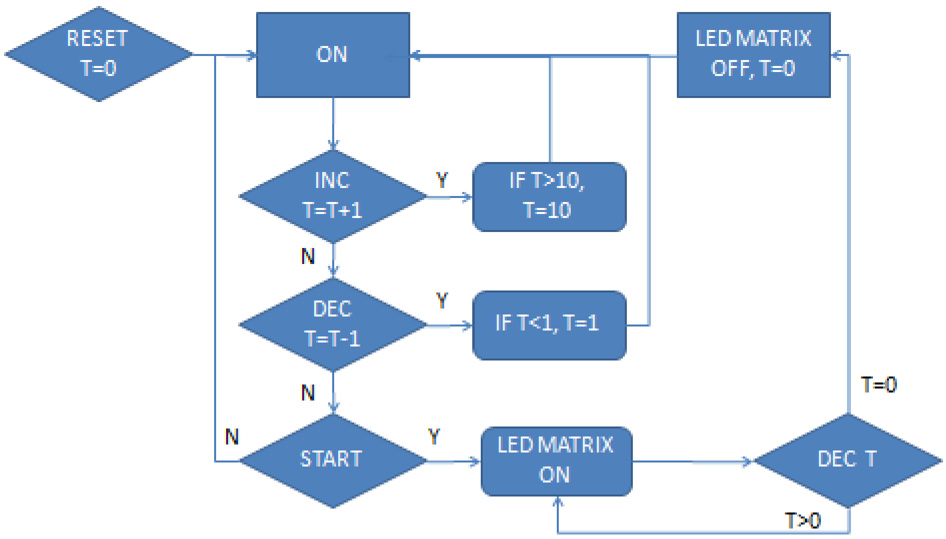

Figure 5. Algorithm Flowchart.

The INC and DEC buttons feature similar and opposite functions. When pressed, a counter will be incremented or decremented, according to the button. The program also ensures that this counter never exceeds 10 and is never smaller than 0. There is also a filter button, responsible for not letting outside interference to disturb the signal that will be sent to the microcontroller. Whenever pressed, the display bar-shaped LED's will be upgraded for better viewing by the user.

When the START button is pressed the interruption of the Timer 0 is configured. To time 1 second, the TMR0 was started with the decimal value 6 and the auxiliary multiplier K with a value of 125, according to equation 2. The OPTION_REG register has been configured with a divider PRESCALER 256. To time one minute, one second multiplier was used with the value of 60. According to the value of the counter, which was incremented or decremented, the interruption of timer 0 will time "x" minutes. When the time reaches 0, or the RESET button is pressed, the program returns to the beginning and erases the LED´s matrix.

The electric diagram of the device was also reproduced in EAGLE software and is shown in Figure 6. In this scheme, the voltage regulator and the entrance to the battery that will feed the microcontroller are available.

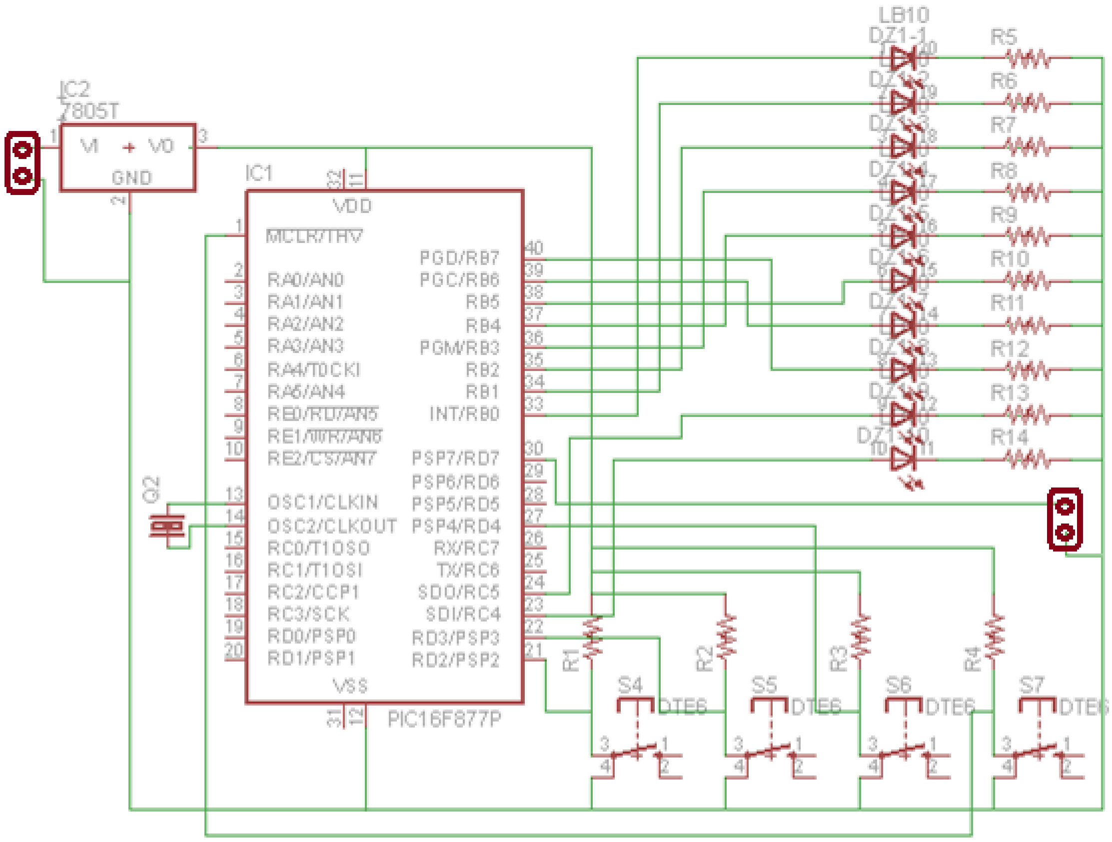

Figure 6. Electrical Diagram of the second microcontroller system for the matrix of LED's.

From this diagram, it was possible to design the PCI with all components arranged on the board and their respective tracks, shown in Figure 7.

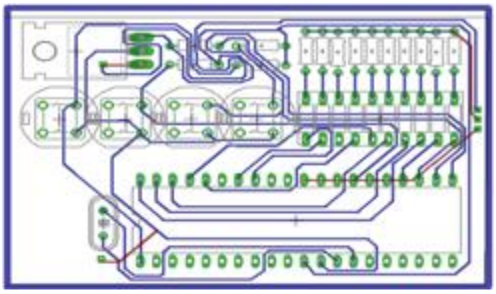

Figure 7. Design of PCI circuit.

Finally we have the prototype in its final phase in Figure 8. On the left side is presented the system off, and on the right left, the system working. To finalize the project, some adjustments are still needed, as a construction of a support for the device and the interfacing of the microcontrolled plate with the LED´s matrixes.

Figure 8. Finalized prototype. On the left side, the system is off, and on the right side, it is working.

5. FINAL CONSIDERATIONS

Through this work it was possible to observe how a simple technology can bring many benefits if used correctly. As LED technology is a cheap and promising, it is extremely necessary to conduct research in all areas of knowledge. Here, we combine physical, biological and electronic knowledge to build a prototype of microcontrolled Phototherapy device to be used in treatment of oral mucositis. The implementation of this prototype to control the time was satisfactory. It is possible to expand this work with the commitment of professionals from other fields, especially medicine, to put the implementation of this technique in practice.

In addition to being used for the treatment of oral mucositis, this prototype can also be employed in the Unified Health System (SUS) for the treatment of wound healing processes in cases of accident or surgeries, due to the fact that it is a non-invasive and low cost technique. The Phototherapy using LED´s based systems could decrease or even eliminate the use of medications such as painkillers and anti-inflammatory drugs.

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ATTACHMENTS

Annex I: Table with the algorithm in assembly language developed for this project.

```
#INCLUDE <P16F877A.INC>
__CONFIG _CP_OFF & _CPD_OFF & _DEBUG_OFF & _LVP_OFF & _WRT_OFF & _BODEN_ON & _PWRTE_ON & _WDT_OFF & _HS_OSC

CBLOCK  0X20
        C1
        C2
        C3
        CONT
        TEMPO1
        TEMPO2
        MULT1
        MULT2
        ENDC

#DEFINE BANK1   BSF     STATUS,RP0
#DEFINE BANK0   BCF     STATUS,RP0

#DEFINE INC     PORTD,2
#DEFINE DEC     PORTD,3
#DEFINE START   PORTD,4
#DEFINE MATRIZ  PORTD,7

MOVLF   MACRO   N,L
        MOVLW   N
        MOVWF   L
ENDM

ORG     0X0000 ; VETOR DE RESET
GOTO    INICIO

ORG 0x0004 ; VETOR DE INTERRUPÇÕES
BCF     INTCON,T0IF
```

```
        MOVLF   D'6',TMR0
        DECFSZ  MULT1
        RETFIE
        MOVLF   D'125',MULT1
        DECFSZ  MULT2
        RETFIE
        MOVLF   D'60',MULT2
        DECFSZ  CONT
        GOTO    ANOVE
        GOTO    AZERO

ANOVE   MOVF    CONT,W
        SUBLW   D'9'
        BTFSS   STATUS,Z
        GOTO    AOITO
        MOVLF   B'11111111',PORTB
        MOVLF   B'10000001',PORTD
        RETFIE

AOITO   MOVF    CONT,W
        SUBLW   D'8'
        BTFSS   STATUS,Z
        GOTO    ASETE
        MOVLF   B'11111111',PORTB
        MOVLF   B'10000000',PORTD
        RETFIE

ASETE   MOVF    CONT,W
        SUBLW   D'7'
        BTFSS   STATUS,Z
        GOTO    ASEIS
        MOVLF   B'01111111',PORTB
        RETFIE

ASEIS   MOVF    CONT,W
        SUBLW   D'6'
        BTFSS   STATUS,Z
        GOTO    ACINCO
        MOVLF   B'00111111',PORTB
        RETFIE

ACINCO  MOVF    CONT,W
        SUBLW   D'5'
        BTFSS   STATUS,Z
        GOTO    AQUATRO
        MOVLF   B'00011111',PORTB
        RETFIE

AQUATRO MOVF    CONT,W
        SUBLW   D'4'
        BTFSS   STATUS,Z
        GOTO    ATRES
        MOVLF   B'00001111',PORTB
        RETFIE

ATRES   MOVF    CONT,W
        SUBLW   D'3'
        BTFSS   STATUS,Z
        GOTO    ADOIS
        MOVLF   B'00000111',PORTB
        RETFIE

ADOIS   MOVF    CONT,W
        SUBLW   D'2'
        BTFSS   STATUS,Z
        GOTO    AUM
        MOVLF   B'00000011',PORTB
        RETFIE

AUM     MOVF    CONT,W
        SUBLW   D'1'
        BTFSS   STATUS,Z
        GOTO    AZERO
        MOVLF   B'00000001',PORTB
        RETFIE

AZERO   BCF     MATRIZ
        CLRF    PORTB
        CLRF    PORTD
        BCF     INTCON,T0IE
        RETFIE

;*****************************************************************

INICIO  BANK1
        MOVLF   H'00',TRISB
        MOVLF   B'00011100',TRISD
        BANK0
        MOVLF   H'00',PORTB
        MOVLF   H'00',PORTD
        MOVLF   D'0',CONT

L0      BTFSC   INC
        GOTO    L1
        BTFSS   INC
        GOTO    $-1
        CALL    TIME
        GOTO    UP

L1      BTFSC   DEC
        GOTO    L2
        BTFSS   DEC
        GOTO    $-1
        CALL    TIME
        GOTO    DOWN

L2      BTFSC   START
        GOTO    L0
        BTFSS   START
        GOTO    $-1
        CALL    TIME

        BANK0
        MOVLW   0X00
        XORWF   CONT,0
        BTFSC   STATUS,2 ;
        GOTO L0

        BANK1
        MOVLW   B'00000101'
        MOVWF   OPTION_REG
        MOVLW   B'10100000'
        MOVWF   INTCON
        BANK0
        MOVLF   D'125',MULT1
        MOVLF   D'60',MULT2
        MOVLF   D'6',TMR0
        BSF     MATRIZ
        BTFSC   MATRIZ
        GOTO    $-1
        GOTO    L0

UP      INCF    CONT,F
        MOVF    CONT,W
        SUBLW   D'11'
        BTFSS   STATUS,Z
        GOTO    ZERO
        MOVLF   D'10',CONT
        GOTO    ZERO

DOWN    DECF    CONT,F
        MOVF    CONT,W
        SUBLW   D'255'
        BTFSS   STATUS,Z
```

```
        GOTO    ZERO
        MOVLF   D'0',CONT
        GOTO    ZERO

;******************************************************************

ZERO    MOVF    CONT,W
        SUBLW   D'0'
        BTFSS   STATUS,Z
        GOTO    UM
        MOVLF   H'00',PORTB
        MOVLF   H'00',PORTD
        GOTO    L0

UM      MOVF    CONT,W
        SUBLW   D'1'
        BTFSS   STATUS,Z
        GOTO    DOIS
        MOVLF   B'00000001',PORTB
        MOVLF   H'00',PORTD
        GOTO    L0

DOIS    MOVF    CONT,W
        SUBLW   D'2'
        BTFSS   STATUS,Z
        GOTO    TRES
        MOVLF   B'00000011',PORTB
        MOVLF   H'00',PORTD
        GOTO    L0

TRES    MOVF    CONT,W
        SUBLW   D'3'
        BTFSS   STATUS,Z
        GOTO    QUATRO
        MOVLF   B'00000111',PORTB
        MOVLF   H'00',PORTD
        GOTO    L0

QUATRO  MOVF    CONT,W
        SUBLW   D'4'
        BTFSS   STATUS,Z
        GOTO    CINCO
        MOVLF   B'00001111',PORTB
        MOVLF   H'00',PORTD
        GOTO    L0

CINCO   MOVF    CONT,W
        SUBLW   D'5'
        BTFSS   STATUS,Z
        GOTO    SEIS
        MOVLF   B'00011111',PORTB
        MOVLF   H'00',PORTD
        GOTO    L0

SEIS    MOVF    CONT,W
        SUBLW   D'6'
        BTFSS   STATUS,Z
        GOTO    SETE
        MOVLF   B'00111111',PORTB
        MOVLF   H'00',PORTD
        GOTO    L0

SETE    MOVF    CONT,W
        SUBLW   D'7'
        BTFSS   STATUS,Z
        GOTO    OITO
        MOVLF   B'01111111',PORTB
        MOVLF   H'00',PORTD
        GOTO    L0

OITO    MOVF    CONT,W
        SUBLW   D'8'
        BTFSS   STATUS,Z
        GOTO    NOVE1
        MOVLF   B'11111111',PORTB
        MOVLF   H'00',PORTD
        GOTO    L0

NOVE    MOVF    CONT,W
        SUBLW   D'9'
        BTFSS   STATUS,Z
        GOTO    DEZ
        MOVLF   B'11111111',PORTB
        MOVLF   B'00000001',PORTD
        GOTO    L0

DEZ     MOVF    CONT,W
        SUBLW   D'10'
        BTFSS   STATUS,Z
        GOTO    L0
        MOVLF   B'11111111',PORTB
        MOVLF   B'00000011',PORTD
        GOTO    L0

;******************************************************************
TIME    ;T_250
        MOVLW   D'5';
        GOTO    T_50

T_50    MOVWF   C3          ;
        MOVLW   D'50'       ;
        MOVWF   C1          ;
        MOVLW   D'50'       ;
        MOVWF   C2          ;
        DECFSZ  C2,F
        GOTO    $-1
        DECFSZ  C1,F
        GOTO    $-3
        DECFSZ  C3,F
        GOTO    $-9
        RETURN

END
```