Functional Specification for a Dynamic Pupil in a Prosthetic Eye

October 18, 2004

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 340 Functional Specifications for a Dynamic Pupil in a Prosthetic Eye

Dear Dr. Rawicz:

The attached document, *Functional Specification for a Dynamic Pupil in a Prosthetic Eye*, outlines the overview of the functional requirements for our project in ENSC 340. The goal of this project is to improve the cosmetic aspects of an artificial eye that replaces the real eye of a patient in circumstances that surgery does not provide necessary means to improve the health of the diseased eye.

Prosthetic eyes have been used to replace fatally diseased human eyes since the beginning of the 19^{th} century. Even though the cosmetic aspects of the artificial eyes have come a long way since its inception, a major short coming still exists in modern designs of these eyes. Ocularists, people who custom-make the prosthetic eyes, have quite improved the cosmetic aspects of these eyes as far as color matching between the real eye and the artificial eye in a patient is concerned, both in the eye ball and the iris. Being able to utilize a dynamic pupil in an artificial eye would tremendously improve the esthetic of such eye and make them very similar to a functioning healthy human eye.

Our team, Dyno I, consists of four talented, enthusiastic and hard-working forth year engineering students. These individuals include: Nima Kokabi, CEO; Houman Hatamian, CFO; Ali Taheri, CTO; and Arash Taheri, COO. Please feel free to contact us at ataheri@sfu.ca if you have any questions.

Sincerely,

Nima Kokabi

Nima Kokabi
CEO
Dyno

Functional Specifications for Dynamic Pupil in a Prosthetic Eye

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Date of Submission: October 18, 2004

Executive Summary

We at Dyno I propose to design a dynamic pupil that will be utilized in a prosthetic eye. This pupil will consist of a custom-made LCD. Furthermore, to control the intensity of the ambient light, we utilize a super small micro controller which will be programmed in a way that when used in conjunction with LCD, the overall system would replicate the functionality of a real pupil. Dyno I consists of four engineering students from Simon Fraser University, who bring extensive experiences and ideas to the design of our project. Our products must be conventional to the highest quality and usability standards. Dyno I will require approximately $2800 in order to fulfill the financial needs of this project. This project is partially founded by Dr. Peter Dolmen, who is one of the most well-known ophthalmologists in the area of research in British Columbia. Moreover, due to the high financial costs, we will try to obtain more funding through SFU as much as possible.

The integration and development of our project contains two different sections. Phase one of our project develops a dynamic pupil utilized in a prosthetic eye. This artificial eye contains an LCD which is sensitive to the intensity of ambient light in its surroundings; therefore, size of the pupil changes according to the intensity of light.

In phase two of our project, Dyno I members try to move the project even further ahead and making it actually practical for future patients.

This document outlines the functional specifications of the first phase of our project at Dyno I.

Table of Contents:

Functional Specification for a Dynamic Pupil in a Prosthetic Eye

1. Introduction:

Prosthetic eyes have been used to replace fatally diseased human eyes since the beginning of the 19th century. Even though the cosmetic aspects of the artificial eyes have come a long way since its inception, a major short coming still exists in modern designs of these eyes. Ocularists, people who custom-make the prosthetic eyes, have quite improved the cosmetic aspects of these eyes as far as color matching between the real eye and the artificial eye in a patient is concerned, both in the eye ball and the iris. Being able to utilize a dynamic pupil in an artificial eye would tremendously improve the esthetic of such eye and make them very similar to a functioning healthy human eye.

1.1. Scope:

This document lists functional requirements for a *Dynamic Pupil in a Prosthetic Eye* for blind and visually impaired people. Furthermore, this document will supply a complete set of the requirements for the first phase of our project at Dyno I.

1.2. Glossary:

This document is provided for managers, designers, and marketing personnel. Managers are able to use this document as a guide for scheduling and other managements. Designers may use this document as a guideline for the development of the system. Finally, marketing personnel may look at this document as a guide for product promotion. We at Dyno I have tried to make this document as easy as possible to understand.

1.3. Conventions:

There are several notations used throughout this document for functional requirement needs. These notations are explained below:

- **[R#]:** This notation points out a functional requirement.

- Numbers at the end of each requirement denote which phase it is applied to:
  - **- (1)** A functional requirement for only Phase one
  - **- (2)** A functional requirement for only Phase two
  - **- (3)** A functional requirement for both Phases one and two

2. System Requirements:

In this part of the document, system requirements, such as physical characteristics and many other functional specifications of our design will be discussed.

2.1. System Overview:

Figure 2.1.1 below illustrates the overall high level design of our dynamic pupil system in a prosthetic eye. The operation begins with a light sensor monitoring the intensity of ambient light around the eye. In fact, the diode converts the light intensity to an electrical signal that can be constantly monitored by a control unit. The control unit in turn controls the LCD that replicates the pupil. This pupil effectively opens up and closes similar to a real pupil according to the intensity of the ambient light. The higher the intensity of the light, the smaller the pupil becomes; as a result, less light is allowed to enter the eye. Similarly the lower the intensity of the light, the larger the pupil diameter becomes which causes more light to enter the eye.

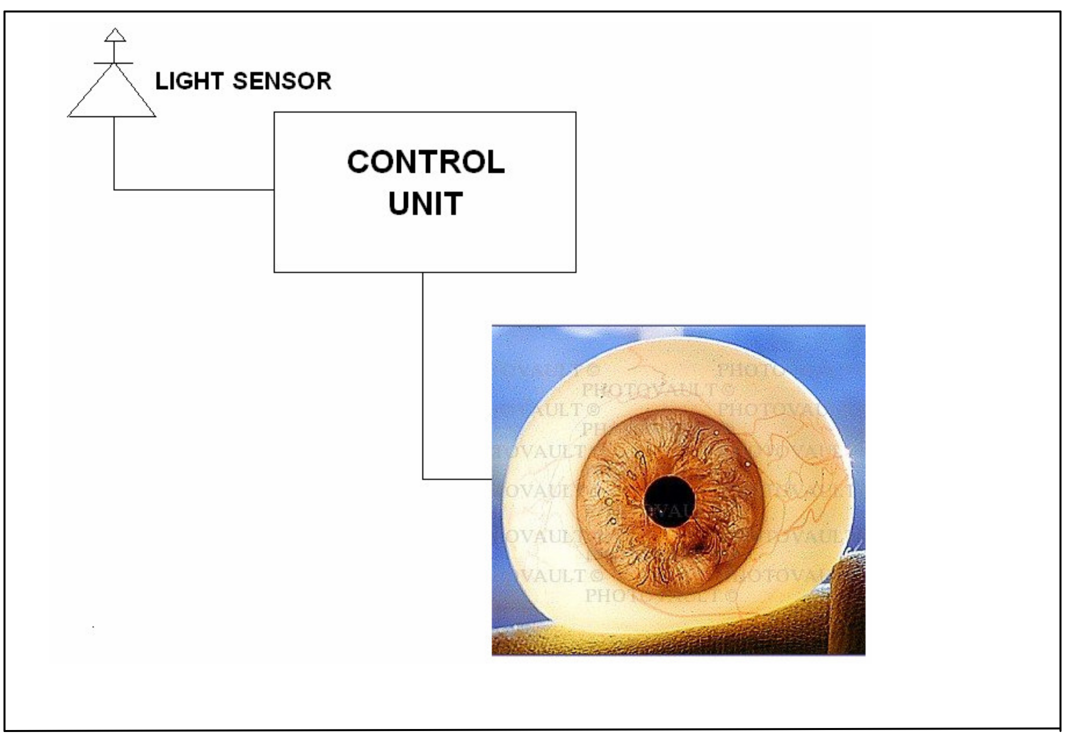


Figure 2.1.1: Overall High Level Design of the Dynamic Pupil System

Figure 2.1.2 illustrates how a typical eye would look at different ambient lights. The eye on the left side is situated in a dim ambient light which has caused the pupil to opens up a great deal. On the other hand, the same eye when placed in a bright environment shows a very small pupil. This is shown in the eye on the right hand side of figure 2.1.2.

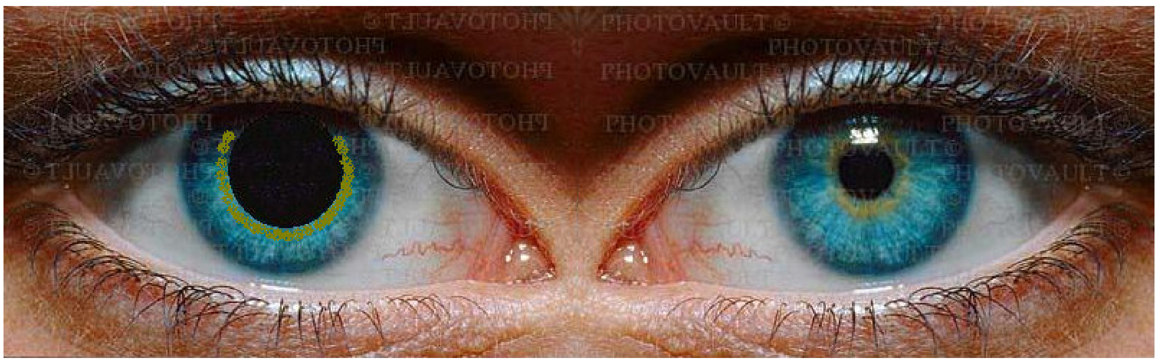


Figure 2.1.2: Illustration of a typical eye at different Ambient Lights

The uniqueness of the dynamic pupil prosthetic designed by Dyno I is that the entire circuitry is so incredibly small that it can be situated in the front portion of the prosthetic eye. The circuitry is also designed to be heat sensitive so that when placed in the initial mold of the artificial eye, it can be easily cured along with mold at high temperature for sterilizing purposes. The small size of this system also bears the advantage of this system being easy to be used by patients. They can use the same procedure used to clean current prosthetic eyes without worrying about any external components or connections.

Figure 2.1.3 on the next page illustrates the overall flow chart of our design. As the figure represents, the photodiode acts as a light sensor in detecting light from the surroundings. The Microcontroller monitors the different intensities of the ambient light. When intensity of light increases, microcontroller notices this difference and forces the size of the pupil to decrease. Furthermore, decreasing the intensity of ambient light forces the size of pupil to increase by the aid of microcontroller. However, when intensity of light stays constant, no difference is detected by the microcontroller; as a result, size of the pupil stays as the same.

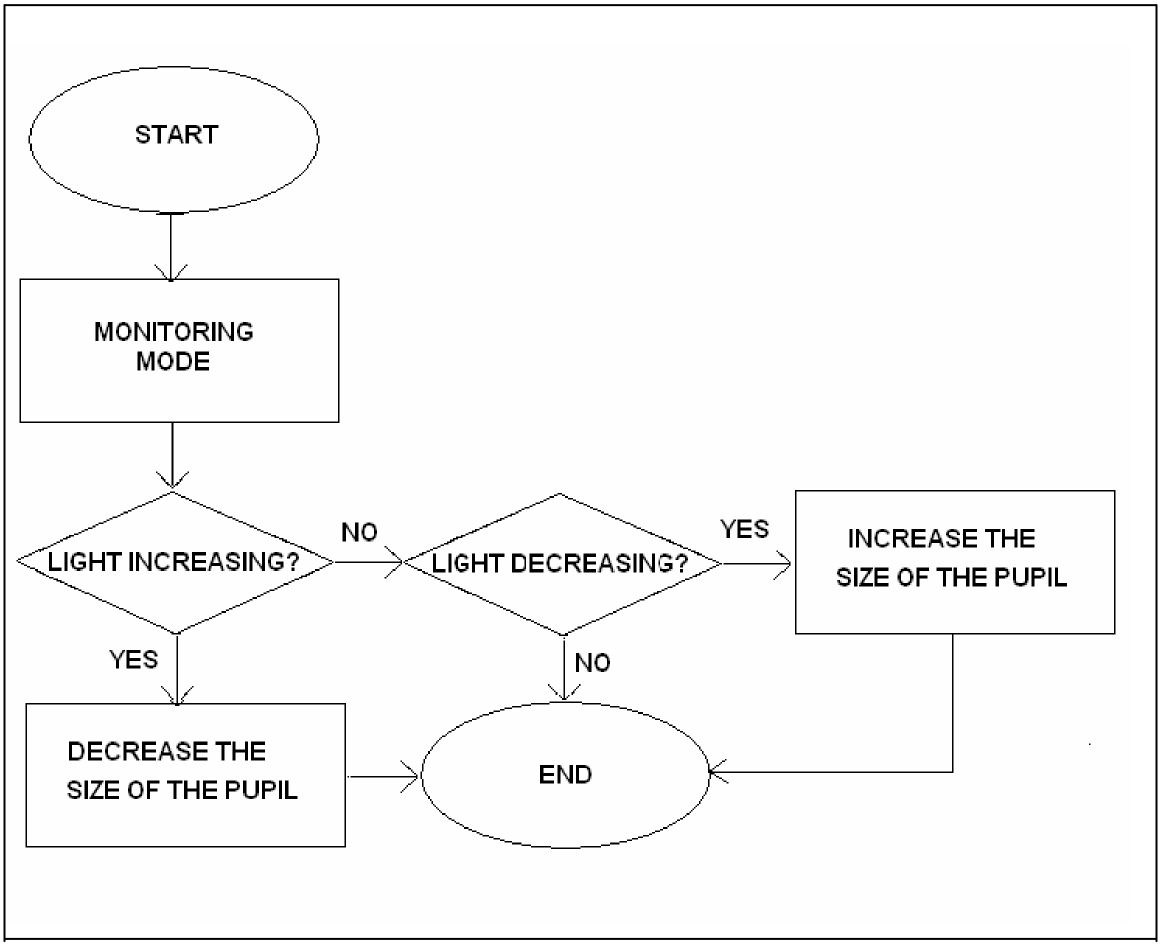


Figure 2.1.3: Overall Flow Chart Design of the Project

The biggest complication faced by our group in designing the dynamic pupil system is that we have to design the whole system, including the battery and the circuit board, small enough that it can be fit into the mold that forms the front of the artificial eye. Figure 2.1.4 on the next page shows the major components of an artificial eye, which consists of an orbital implant as well as the front portion of the artificial eye, which is mainly made by plastic mold, custom-built to fit individual patients.

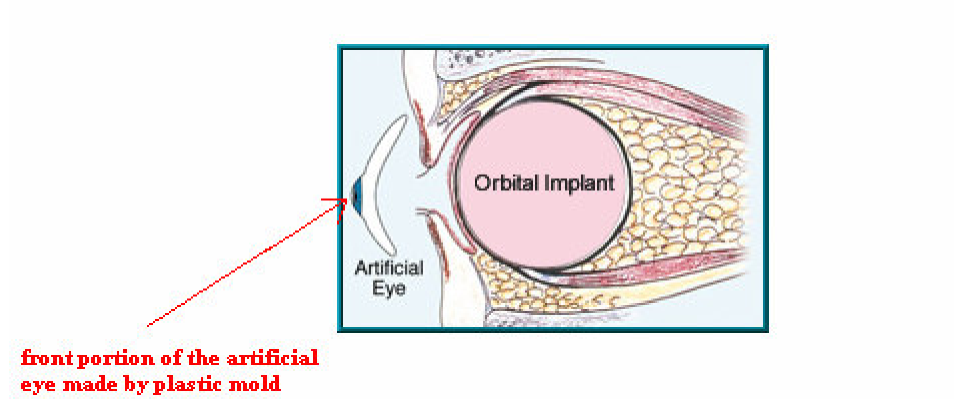


Figure 2.1.4: Major Components of an Artificial Eye

As you can see from the above figure, the front portion of the artificial eye has a very limited space to work around with. The other issue present is that an ocularist uses a rather high temperature of 105^0C for half an hour in order to cure the mold. Therefore, the dynamic pupil system in our case has to withstand this high temperature since it is being situated in the mold before it's been cured. One of the difficulties we had was to find batteries, microcontrollers, as well as custom-made LCDs that would be resistant to this high temperature, which was achieved after hard and long research hours.

Following figure is a block diagram of our proposed design. This design consists of a photodiode, a super small microcontroller, and a custom-made LCD powered by a thermal resistant extended life lithium ion battery. Figure 2.1.5 represents an overview of our design. However, different components of the project will be discussed in much more detail throughout this document.

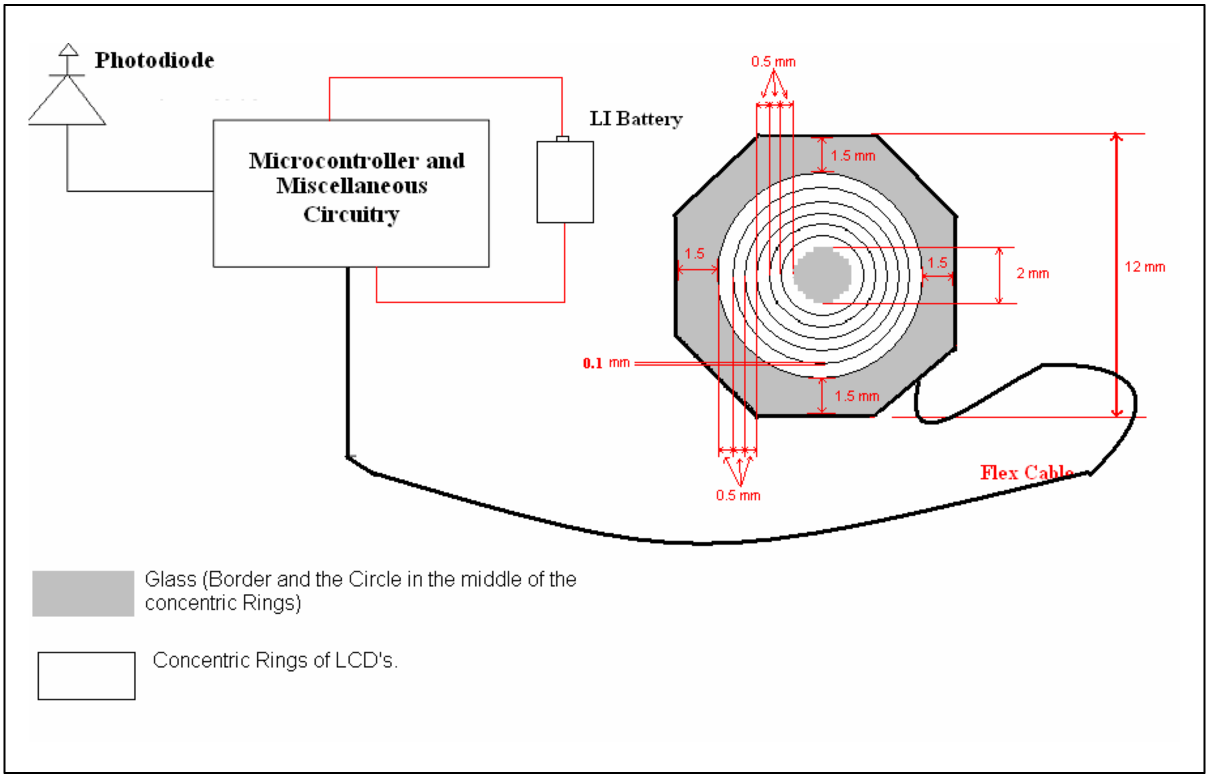


Figure 2.1.5: Overview of Functional Specification Block Diagrams

2.2. Physical Requirements:

In this part of the document the physical requirements of the functional specifications for our design will be discussed. As discussed previously, there exists three main functional blocks in our project: Custom-Made LCD, Photodiode, and Battery.

2.2.1. General:

[R1] In order to have a better design and make the product more practical for the patients, the best thing to do is that the boarders around the concentric rings of LCD be as small as possible. (3)

[R2] The widths of the pin ledges are preferred to be as small as possible in order to be able to fit them inside the artificial eye. (3)

[R3] Instead of using pins around the octagonal LCD, a flex cable is used in order to occupy less space. The length of the flex cable is 0.5 mm. (3)

[R4] The width of each concentric ring of LCD is 0.5 mm. The gap between two consecutive rings is 0.03 mm. (3)

[R5] Length of the LCD is about 13.5 mm. The reason that the LCD is decided to be as small as possible is to be able to fit it inside the pupil of an artificial eye in order to make it practical. (3)

[R6] The thickness of the LCD is set to be 1.9 mm. (1)

[R7] The photodiode is preferred to be as small as possible in order to be able to be localized inside the artificial eye. The photodiode's active area is about 4.10 mm^2. The photodiode used in our design is PDB-C139-ND. (3)

[R8] The battery used in our design is preferred to be as small as possible. Furthermore, this battery is capable of having low power consumption. The reason is that artificial eyes used by patients currently should be changed once every two years. Therefore, the batteries used in our LCD should be able to withstand this long period. As a result, they are chosen to have high nominal capacity. (3)

2.3. System Requirements:

2.3.1. General:

[R9] The unit shall be capable of operating at the normal consumer temperature of between 0^0C to105^0C. (1)

[R10] The unit should be able to operate in LPM (Low Power Mode) as well. The reason is that when the patient rests, a lot of energy will be wasted; therefore, it's the best to shut down the whole LCD when the patient doesn't need it. (3)

2.3.2. Performances:

[R11] The photodiode used in our design should have a great amount of sensitivity to the ambient light of the LCD surroundings. The reason is that the main function of our product starts when difference in ambient light is detected by the sensor. Therefore, the more sensitive the photodiode is, the more accurate the LCD performs. (1)

[R12] The size of the LCD should be able to increase or decrease according to the dark or light environments. The size of the LCD should increase when placed in a dark environment and decreased when placed in a light environment, just like a real pupil. (1)

[R13] The batteries used in our design should be able to work in a period of two years. As a result, they should have high nominal capacity. (3)

[R14] The microcontroller should be able to go to LPM (Low Power Mode) when the patient is sleeping with close eyes. It should also be able to switch back to regular mode, when the patient opens his/her eye(s). This function of the microcontroller will also help the batteries to prevent them from being wasted. In fact, the microcontroller should be able to sample each second to see if the eye is placed in the darkest environment possible. If so, the whole system should shut down. On the other hand, when the patient opens his/her eye(s), the unit should be capable of detecting light and changing back to the regular mode. (3)

[R15] It is necessary to use an external crystal with the MSP430F413IPM because it will be used as the MCLK, to calibrate the DCO, or to run on in low power mode. The 32,768 kHz crystal is used in the FLL of the MSP430x4xx to automatically calibrate DCO. (1)

2.3.3. User Interface:

[R16] One of the best features of our dynamic pupil product is its user friendly interface. In fact, the user (patient) doesn't need to bother him/her with punching buttons in order to be able to communicate with the product. The patient only needs to do a surgery in order to place the artificial eye on his/her face. The reason is that, as mentioned previously, our product has the ability to distinguish between the dark and light environments. As a result, our product performs its work whenever necessary and shuts down when the patient is in sleep. (3)

2.3.4. Serviceability:

[R17] The unit should be exchanged after a period of two years. (3)

2.3.5. Communication:

[R18] The communication is functioned between the photodiode and the Custom-Made LCD by the aid of microcontroller. (1)

[R19] The main and only communication is between the light sensor and the LCD. (1)

[R20] The photodiode detects the ambient light from the surroundings and passes the data to the microcontroller. (1)

[R21] The microcontroller processes the data. It compares the new values received from the photodiode with the old values stored. (1)

[R22] By comparing the old values with the new ones, the microcontroller decides what task should be performed. For example, if the microcontroller senses that the intensity of light is increased, it decides that the size of the pupil should be decreased. (1)

[R23] When the microcontroller chooses the task to be performed, it communicates with the LCD. Basically, it will send a message to the LCD and orders the pupil to increase or decrease according to the task. (1)

[R24] Communication part of our product is done by computer programming. There are three languages in which the microcontroller can be programmed: Assembly Language, C, and C++. We at Dyno I, decided to use C in programming our microcontroller. (1)

[R25] After the microcontroller sends the message to the LCD, the size of the pupil increases or decreases accordingly. (1)

The following table represents the several features of our microcontroller:

Table 2.3.5.1: Several Features of MSP430 Microcontroller

- Low Supply-Voltage Range, 1.8 V . . . 3.6 V
- Ultralow-Power Consumption:
  - Active Mode: 200 µA at 1 MHz, 2.2 V
  - Standby Mode: 0.7 µA
  - Off Mode (RAM Retention): 0.1 µA
- Five Power-Saving Modes
- Wake-Up From Standby Mode in less than 6 µs
- Frequency-Locked Loop, FLL+
- 16-Bit RISC Architecture, 125-ns Instruction Cycle Time
- 16-Bit Timer_A With Three† or Five‡ Capture/Compare Registers
- Integrated LCD Driver for 96 Segments
- On-Chip Comparator
- Brownout Detector
- Supply Voltage Supervisor/Monitor - Programmable Level Detection on MSP430F415/417 devices only
- Serial Onboard Programming, No External Programming Voltage Needed Programmable Code Protection by Security Fuse
- Bootstrap Loader in Flash Devices
- Family Members Include:
  - MSP430C412: 4KB ROM, 256B RAM
  - MSP430C413: 8KB ROM, 256B RAM
  - MSP430F412: 4KB + 256B Flash 256B RAM
  - MSP430F413: 8KB + 256B Flash 256B RAM
  - MSP430F415: 16KB + 256B Flash 512B RAM
  - MSP430F417: 32KB + 256B Flash 1KB RAM
- Available in 64-Pin Quad Flat Pack (QFP) and 64-pin QFN
- For Complete Module Descriptions, Refer to the *MSP430x4xx Family User's Guide*, Literature Number SLAU056

(Source: Texas Instruments Manual for MSP430 Series)

The Texas Instruments MSP430 family of ultra low power microcontrollers consists of several devices featuring different sets of peripherals targeted for various applications. The architecture, combined with five low power modes is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that attribute to maximum code efficiency.

The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 6µs. The MSP430x41x series are microcontroller configurations with one or two built-in 16-bit timers, a comparator, 96 LCD segment drive capability, and 48 I/O pins. Typical applications include sensor systems that capture analog signals, convert them to digital values, and process the data and transmit them to a host system. The comparator and timer make the configurations ideal for industrial meters, counter applications, handheld meters, etc. **(Source: TI Manual Book for MSP430 Series)**

The pin lay out of the microcontroller is shown in Figure 2.3.5.1 below:

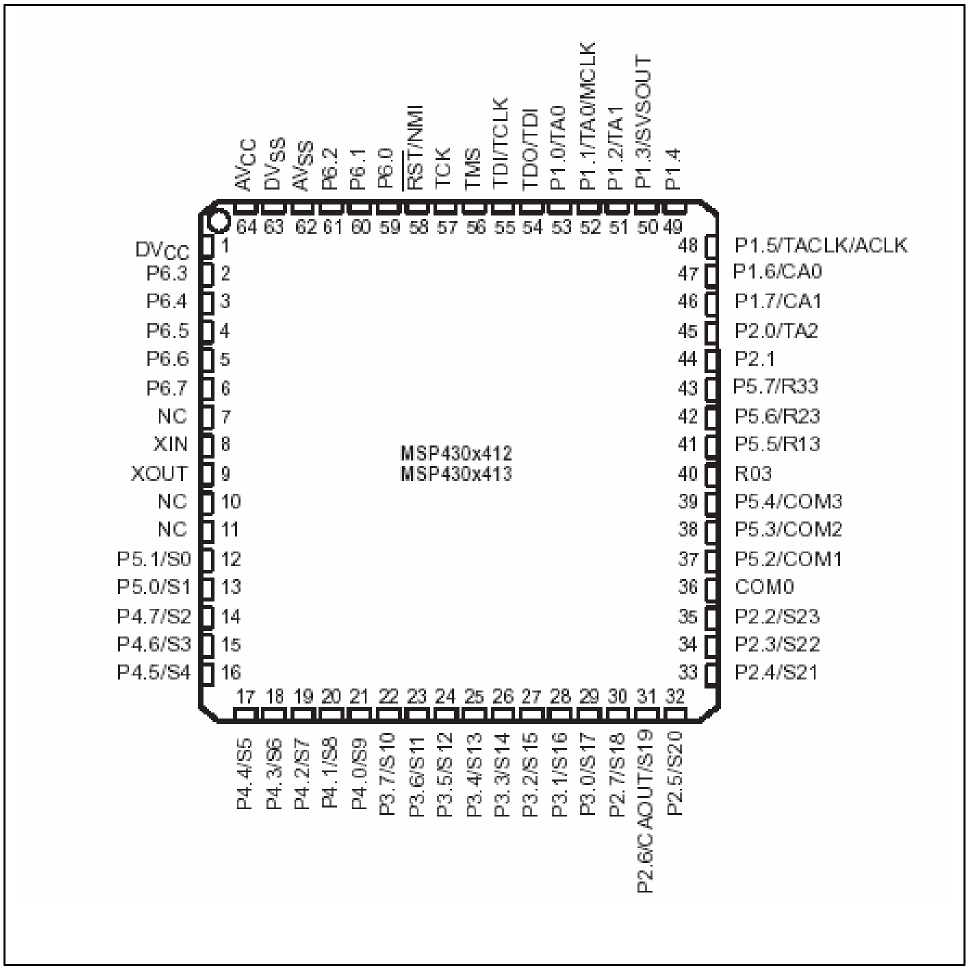


Figure 2.3.5.1: Pin Layout Representation of the MSP430 Microcontroller

2.3.6. Test Plan:

The product should be divided and tested in some dark and light environments before integration. Moreover, further testing shall be performed during integration of components in order to ensure proper communication between the subsystem in our product.

2.3.6.1. Communication Testing:

In order to ensure proper communication between the subsystems within our product, some tests shall be applied to the system. One of the main tests that should be performed is dynamicity of the pupil in different environments.

In order to perform this test, when the device is ready, it should be taken to dark and light environments. By increasing the intensity of light, the pupil of the artificial eye should decrease in size. On the other hand, by taking the product to darker environments, the size of the pupil is expected to increase.

Another important test before integration of our product is to test the LPM (Low Power Mode) capability of our device. As mentioned previously, one of the features of our device is to shut down the whole system when there is absolutely no light in the surroundings, which is when the patient closes his/her eye(s). This feature will allow the battery to survive longer time by not wasting the power. In fact, whenever the patients go to sleep by closing the eyes, no light will be detected by the photodiode. As a result, the microcontroller shuts down the whole device and prevents loss of power. On the other hand, by closing the eyes, intensity of ambient light increases; as a result, system goes back to its original mode. This test shall be performed by the emulator provided from TI.

3. Design Overview:

There are three main parts in our product other than the Microcontroller, which is the communicator: Custom-Made LCD, Battery, and Photodiode. The following figures illustrate each part:

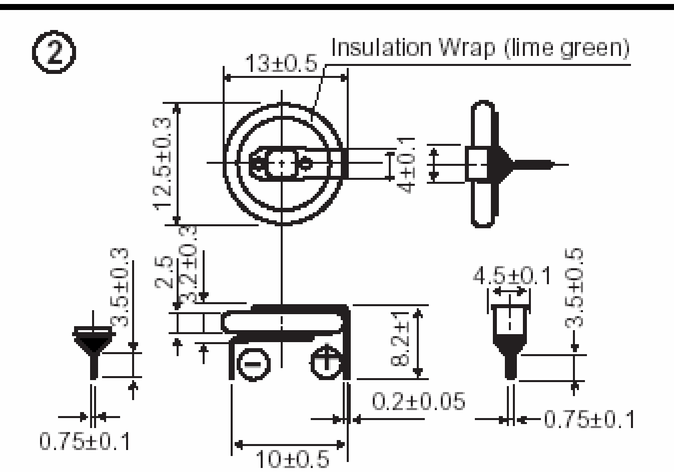
Model No.	Dimensions/mm
BR1225A/HB	

Figure 3.1: Model Number and Dimensions of the Battery used in our Design

Photo Detectors

Fig.	Active Area (mm sq)	Short Circuit Current (Isc) (uA) Typ.	Dark Current (Id) (nA) Max	Sensitivity Wavelength (nm) Min.	Peak	Max.	Junction Capacitance (pF) Typ.	Response RL=1KOhm (ns) Typ.	Viewing Angle (2x Theta)	Digi-Key Part No.	Price Each 1	25	100	250
Blue Enhanced PhotoConductive Detectors, Curve Line B														
2	4.10	67	30	400	950	1100	18	50	61	PDB-C139-ND	1.50	1.45	1.37	1.30

Fig. 2 – Flat Top

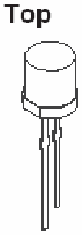


Figure 3.2: Specifications of PDB-C139-ND Photo-Diode

■ **Mechanical Specifications**

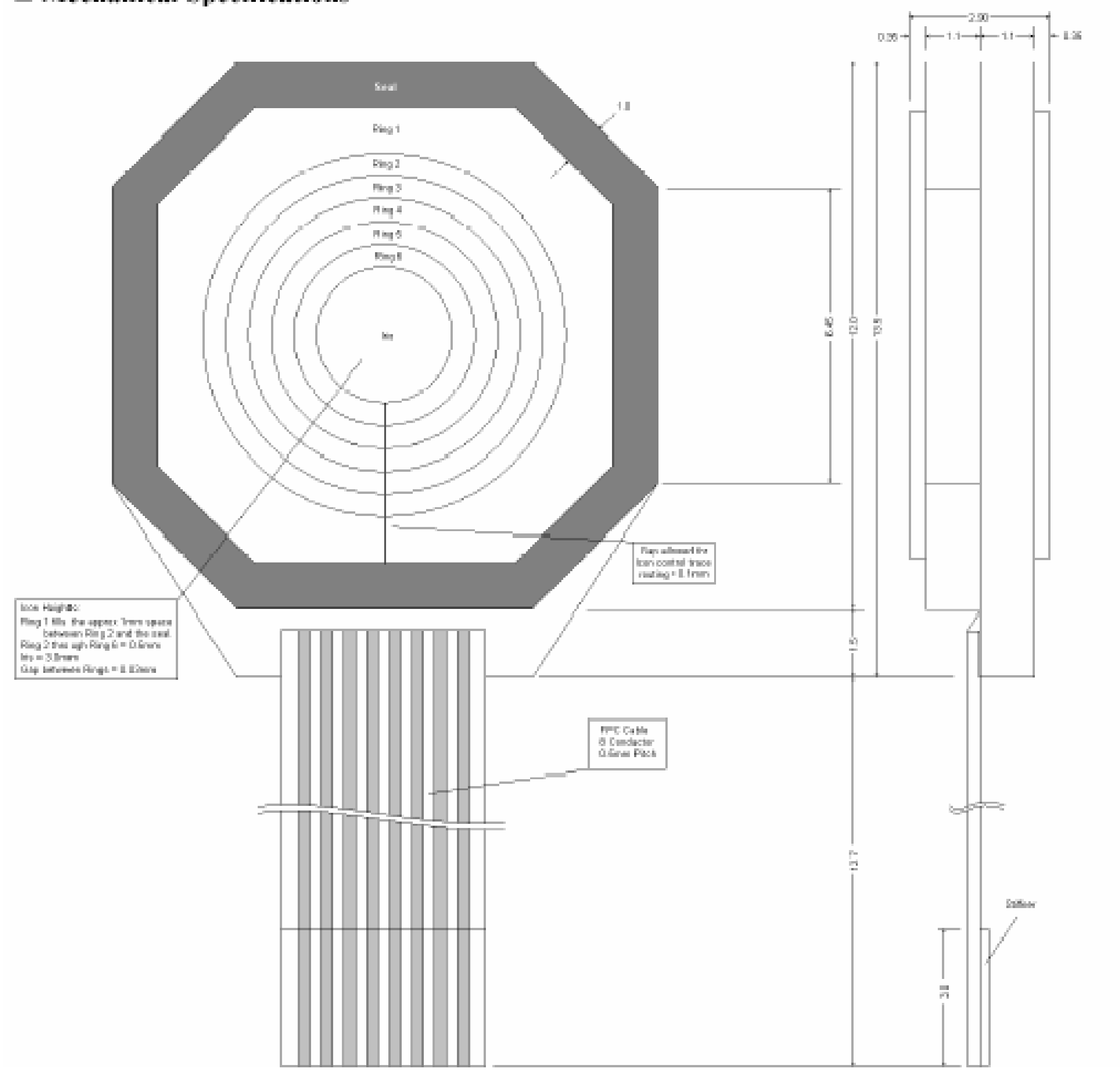


Figure 3.3: Mechanical Features of the Custom-Made LCD

4. Conclusions:

The functional requirements for *Dynamic Pupil System* have been outlined in this document. The requirements given in this document are tentative and should be modified as necessary throughout the completion of the project. Furthermore, this document will provide a clear guideline to the completion of the product.

Our goal is to complete the first phase of the project by mid December 2004. Then, we will plan to incorporate some features of the second phase and make it practical for future patients as soon as possible.

We at Dyno I, hope these functional specifications will provide our audiences with essential insights of our product

5. References:

- http://dkc3.digikey.com/PDF/T043/1367.pdf
- Texas Instruments Manual Book for MSP430 Series Micro-Controller