Ophthalmic Dose Compliance Monitor

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Abstract

It has been proposed to design and miniaturize an ophthalmic dose compliance monitor. The monitor will measure patient compliance by recording each time an ophthalmic dose is administered. The device will do this by sensing when the cap of the bottle has been removed and when the bottle has been rotated past 180 degrees. The current device must be miniaturized and discretely placed on the outside of a medication bottle. A data transfer system must also be incorporated into the device so that each recording of the date and time of administration will be displayed on a computer for study.

Problem Statement

Our objective is to develop and miniaturize a dose compliance monitor that would record (unknown to the client) when (date and time) a topical ophthalmic medication was delivered. There are currently older designs of compliance monitors designed for ophthalmic medications, but our design should be a cost effective, improved model. Ideally we would be able to manufacture approximately 10 of these devices for use in studies. It could be as simple as some of the older models that recorded when the top of the bottle was removed and the bottle was inverted. Maintenance of sterility of the medication is imperative.

Motivation

The purpose of building a dose compliance monitor is to determine how accurately patients follow prescription orders given by their physician. Ophthalmic medication is often prescribed for a duration of 4-6 weeks. Our client, Dr. Murphy, would like to know how compliant pet owners are in order to determine the most effective treatment plans possible. For instance, if compliance is found to be low our client may elect to perform surgery on the animal's eye rather than waiting 4-6 weeks to discover that the medication was not administered properly and the animal's health has decreased. Many diseases of the eye need to be cured as soon as possible before irreversible damage occurs. Our client is trying to determine how he can best treat his patient's.

Client Requirements

The ophthalmic dose compliance monitor's most important client requirement is that it be able to record the date and time of each administered dose. The device, which will be located on bottle, must be discrete and disguised enough that the user does not alter their dose administrations. In order for this to happen, the monitor needs to be small enough to fit on the outside of the medication bottle. The device must maintain the sterility of the medication. In order to do this, no part of the device can touch the inside of the cap or bottle. This client requirement is important because of the legal action that could be taken against him if harm was caused after the administration of medicine from a bottle with our device on it. Also, in order for the client to use the information, the administered dosage data must have the ability to be transferred to a computer for ease of use. Finally, our client would like the price of each bottle to be one hundred dollars or less.

Background Information

This project was initiated in the fall of 2005 by a previous group of biomedical engineering students. As our group began to move forward from their progress we had to do much research. We were given a breadboard containing a circuit which would record the date and time of a dose if the circuit registered that the bottle cap had been displaced and the bottle had been rotated past 180 degrees. The circuit contains many elements which needed to be thoroughly researched so that our group could understand what work had already been completed. A schematic of the circuit can be seen in Figure 1.

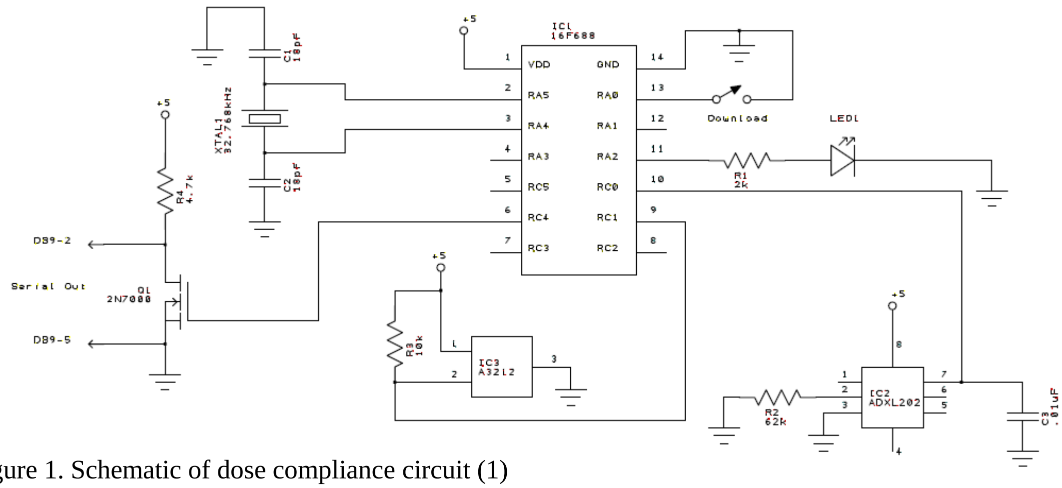

Figure 1. Schematic of dose compliance circuit (1)

Microprocessor

The element in the circuit that records and stores the data for each administered dose is the PIC 16F688 I/P microprocessor. A microprocessor is essential to the project as it is the part that integrates the signals from the sensors located on the eye drop bottle and decides when a dose has been administered. The microprocessor is programmed to store information if and only if it receives both an input for cap displacement and bottle tilt. This specific processor has a memory which is able to store 256 bytes. This low power microprocessor has 14 pins which connect to the power supply, ground and various other circuit inputs, including the sensors which indicate that the cap has been displaced or that the bottle has been rotated. A visual of the microchip is shown in Figure 2. (2)

Figure 2. Photograph of a PIC microchip (2)

Magnetic Sensor

The ophthalmic dose compliance device needs to monitor the times that the cap has been removed from the bottle to accurately determine when the medication is applied. The magnetic sensor accomplishes this goal by utilizing the Hall Effect. This principle explains that when current is placed into a magnetic field, voltages are produced at right angles to both the current and magnetic field vectors. The “Hall” sensor that has been chosen is the A3211 Magnetic Field Sensor produced by Alegro. The sensor is shown in the figure below (Figure 3) and is only two by two millimeters, a size small enough to be discretely hidden on the medication bottle (3).

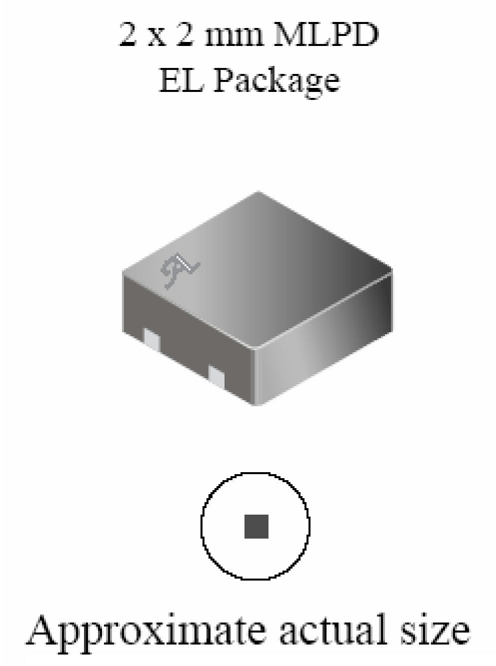

Figure 3: Magnetic sensor appearance (3)

The actual sensor will be placed slightly below the cap of the bottle, on the exterior surface of the bottle. The magnet that will provide the magnetic field will be located directly above the sensor on the cap. The sensor monitors the cap being on and off by providing an output voltage of approximately five volts when the sensor is not in the presence of a magnetic field. When in the presence of a magnetic field, the sensor does not produce an output voltage. The magnetic field that needs to exist to register a “cap on” reading is approximately 37 Gauss (3). The magnet used in last year’s testing had to be about 1 cm away from the sensor in order to register a “cap off” reading. A smaller magnet made of Ba-ferrite Sr-ferrite, having a strength of 60 -70 Gauss, will mostly likely be purchased and further tests will have to be conducted to explore how far away the magnet must be from the sensor in order to induce a signal.

Power Source

The current circuit has been tested using a standard electrical outlet. Eventually the device will have to be independently powered as the bottle will not be attached to anything. The Power Fab CPF 080809L surface mounted rechargeable battery was chosen to power the device. This battery was chosen for its small size, surface mounting capabilities, and its power saving feature. The battery is 8 mm x 8 mm with a thickness of .9 mm. It produces a nominal voltage of 3.8 Volts. It works with RFID tags and other low power applications and recharges to 75% capacity after only twenty minutes. The battery works for data retention, data logging, time and date stamps, and sensing. These functions meet the needs of our device (4). The battery can be seen below in Figure 4.

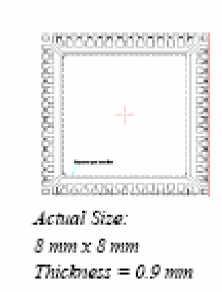

Figure 4: Picture and dimensions of surface mounted rechargeable battery

Data Transfer Options

An important component to our design is the data transfer from the device to a computer. The current method of receiving data from the device is to use a serial cable. This was ideal for the large circuit from last semester since two leads could be placed easily into the breadboard and then the serial cord could be placed into the serial port on the computer. However, for our miniaturized design, this may not be ideal. For this reason, we have come up with two other options of data transfer. These two options are

RFID and Free-Space optics, both of which are wireless. All three of these options will be discussed in greater detail in the following sections.

Data Transfer Option #1: Serial Cable

The serial cable has already been implemented in the design. It is a serial cable that will fit into a 9-pin serial port on a computer. If the computer or laptop being used does not have a serial port (as some of the newer laptops do not) it is not a problem. A USB connection piece would need to be purchased to connect the serial cable to the computer. The serial cable/port way of transferring data has been around for decades. The older serial cables send data at about 1,920 bytes/sec and the newer cables send data at about 11,520 bytes/sec. Since our microprocessor only holds 256 bytes of data, this cable will transfer the data very fast (in approximately .13 seconds). (5)

Figure 5. This figure above shows the serial port (we will be using the 2 smaller 9-bit ports on the bottom) (5)

There are a few pros and one large con that this particular design option presents. The major pro is that it has been previously implemented in the design, and so the computer program on the microprocessor and the computer will not need to be altered. It also has a very fast transfer time and is very inexpensive, only about $10 and this would be a one time cost (6). The major drawback to this design is that placing two leads from the serial cable to the miniaturized circuit will be very difficult. Dr. Murphy will be acquiring the data from the device, and this process should be relatively simple and easy. We feel that this current method would not be simple or easy, but rather very difficult.

Data Transfer Option #2: RFID Data Transmission System

For our second design option we decided to set up a Radio Frequency Identification (RFID) transmission system. RFID is a simple technology that allows for the transfer of simple information wirelessly. There are two basic components to the RFID system: the RFID tag and the RFID reader. The tag stores information while the reader scans and retrieves the information from the tag. By placing a tag onto our bottle we should be able to simply and wirelessly transfer the information from the bottle to the reader which will be connected to a computer for data viewing.

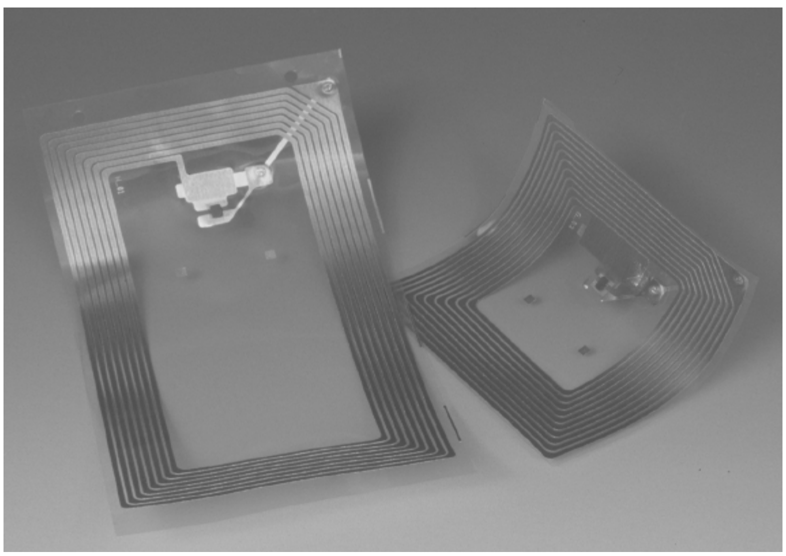

Figure 6. Shows a paper-thin version of an RFID tag. Generally one side of the tag is sticky so it can be adhered to a surface. (7)

RFID tags come in a variety of shapes and sizes, some tags can be as large as a small cell phone, while the smallest can be made into .25 mm^2 (I). This would allow us a variety of options and styles so we could find a tag that best fits our needs, although a small tag will most likely be easier to hide than a large tag. In addition to the size of

RFID tags, tags have the option of being passive or active. Active tags are generally slightly larger, but can carry more information and can transmit data further distances. Passive tags do not store as much information, and have limited transmission distances, but do not require the use of battery power like an active tag does. Hence, by using a passive tag we can increase the longevity of our battery and thus record information for longer periods. Passive tags also allow information storage up to 256 kb, more than 1000 times the storage capacity of the PIC 16F688 I/P microprocessor used in our circuit (7).

A large appeal to the RFID data transmission system is not just its size and data storage, but the overall cost of the RFID tags. RFID tags are remarkably cheap, with companies offering tags for as little at $0.07 per tag when purchased in large quantities (generally 1000 or more). The cost of a reader for a RFID system has a broad range. Readers can be found for as little as $40 or as much as $3000 dollars, depending upon the data transfer speed, distance, power and ease of use. The cost of a reader would be a one time purchase, as only our client would need to have one (8).

Although RFID data transmission sounds simple enough, it will involve some complications to our circuit. One of the largest complications it will bring will be its compatibility with the microprocessor. If the RFID tag was implemented into the circuit, there would have to be a way for the microprocessor to transfer its stored information onto the RFID chip. This could mean shutting off the data storage of the microprocessor completely and relying upon the RFID memory to store the data from the sensors.

Data Transfer Option #3: Free-Space Optical Transmission

For our third design option we proposed a Free-Space Optical Transmission (FSOT) system. FSOT is currently used by NASA and the military to transmit information over long distances quickly and efficiently, generally using laser and UV light. FSOT operates by representing digital information (a sequence of 1's and 0's) as a sequence of flashing light. By turning the light on, it represents a 1, by turning it off it represents a 0. By doing this extremely quickly (as quickly as 10 MHz) one can achieve information transfer as quickly as 10 Mbytes per second. This light display is received and translated back into basic digital information by an optical receiver. The optical receiver (Figure 6) can then be plugged into a computer to create a virtual wire between the light source and computer (9).

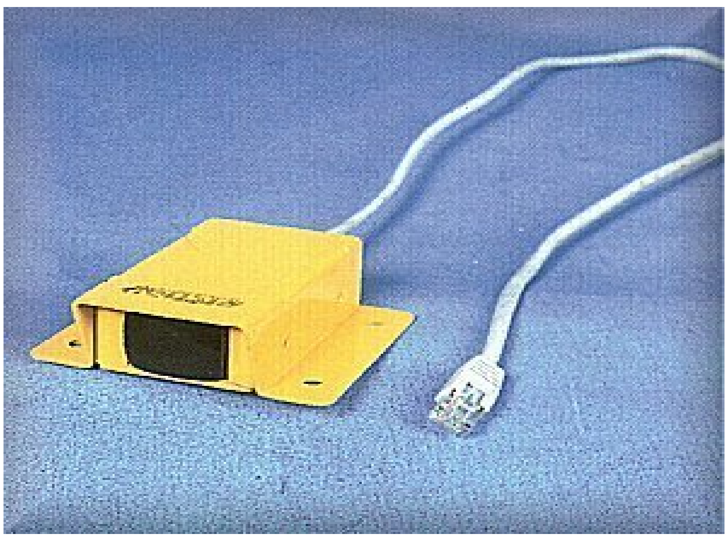

Figure 7. An optical transmitter with Ethernet connection for a computer link. (10)

For our design, a simple LED light will be utilized as the light source. This will allow for relatively fast transfer of information (remember only 256 bytes has to be transferred) while keeping power use down. Although using LED light will not allow for long distance transfer of information, by placing a LED on the bottle we will be able to transfer the information up to 100 cm from the optical receiver or by placing the bottle in a dark enclosure containing the optical receiver. This will minimize interference by room lights or other light sources that may interfere with the data transfer (10).

The cost of this design is inexpensive, with LED lights costing $0.20 per light and $90 for the optical receiver (10). Although many LED lights will have to be purchased; only one receiver will need to be purchased.

A large disadvantage to this design is in its integration into the bottle and circuit. Not only would the LED light need to be integrated into our circuit, but the LED would have to be cleverly disguised on the bottle so that the client's subjects would not be aware of the change in the bottle. This would be difficult to do because a LED light is not a common object to neither find nor hide on an ophthalmic bottle.

Final Design Decision

Our group analyzed each of the three design decisions by ranking each one on the same categories. The categories were chosen based upon the client requirement and each designs ease of use by the client as well as ease of implication. Rankings were given on a scale of 1-5 with 5 being good and 1 being poor. Table 1 shows a decision matrix of each category followed by the design rankings. Each category was decided to be of equal importance and therefore was weighed equally. This was done because no one parameter was stressed by our client and no one parameter would make the design unusable.

Our group decided to move forward with the RFID design. We chose this design as it received the most points in the decision matrix. Some characteristics that set this design apart were its size and ease of use by our client. The transmission of this data is wireless and does not require our client to hook up any leads to the circuit itself. The small size of the RFID tags will be important as the entire device must be hidden on the bottle. Our group will now move forward with our project with continued work on the circuit and integration of an RFID transmission system into it.

	RFID	**Optics**	**Serial Cable**
Cost	5	5	5
Ease of Use	5	4	1
Transfer Speed	5	5	5
Difficulty	4	3	5
Size	5	3	5
Total	**24**	20	21

Table 1. Decision matrix with design rankings based on a scale of 1-5, with 5 being the best ranking.

Future Work

Before we can run tests on the circuit it is necessary for us to order new microcontrollers. After ordering new microcontrollers, model PIC16F688 I/P, from www.mircochip.com at a price of $1.97, we will need to program them. We can program the controllers, with the help of Dan Yee, in the electronics laboratory located at the Medical Sciences building. It is necessary for us to purchase multiple controllers because previous tests have resulted in the overheating of circuit elements, specifically the microcontroller in the latest attempts to test the circuit. Thus, in order to ensure that we have the capabilities to test the circuit in the event that another microcontroller overheats, we will order between 3 and 5. The low cost of the microcontrollers allows us to plan ahead for the event that we may need multiple microcontrollers before the circuit has been fully tested and we have confidence that it is in working order.

After testing the circuit and ensuring the integrity of the design we can begin the process of miniaturizing it. To miniaturize the circuit we plan to use software provided by ExpressPCB from their website, www.ExpressPCB.com. There are two programs needed to miniaturize the circuit, ExpressSCH and ExpressPCB. The first program, ExpressSCH is a schematic design program. The other, ExpressPCB, allows us to design our circuit board. A printed circuit board is a thin board to which electronic components are fixed by solder. (11). Solder is an alloy (usually lead and tin) used to join electrical parts together to form an electrical connection. (12). We have the option of designing either a two sided or four sided circuit board. We chose to utilize the two sided circuit board.

There are multiple steps in designing the PCB with the ExpressPCB computer software. We first place the components and then lay the power and ground traces. A common way to do this, as explained by Professor Willis Tompkins, is to place the components on one side of the board while running the connections on the other.(13) The connections, or network of wires, are referred to as, "the conductor pattern and provide the electrical connections between the components mounted on the PCB"(14). After double checking our printed circuit board design we must then work through our circuit design schematic to ensure that our board layout is exactly the same as our schematic. A more detailed outline of this process is available at www.expresspcb.com. ExpressPCB currently offers to manufacture three 2.5" x 3.8" boards for $51. (11)These boards are clearly larger than what our design requires. In order to take advantage of the low cost of these boards we can print multiple copies of our circuit on a single board. (13)

If ExpressPCB does not work out we can find vendors to quote our board at www.pcbmarketplace.com. Also, Printed Circuit Design magazine has a buyer's guide that would be helpful. Some alternative companies are Sierra Proto Express and Proto Engineering.

We have also compiled a list of companies where we can order small quantities of surface mount components incase we can not obtain everything needed through the parts shop. Some of those companies are Digi-Key, Newark, and Keytronics. (14)

While miniaturizing the circuit, our team will look into the possibility of creating a false bottom for the eye dropper bottle that can encapsulate the circuit, power source, and RFID. This false bottom will then be covered by either a neoprene or plastic shrink sleeve.

The neoprene sleeve is much like a can cooler placed over the circuit components in order to disguise them from the user. The plastic shrink sleeve is a more attractive option; in that it inconspicuous when compared to the neoprene sleeve option. A thin plastic film is placed over the bottle and then by applying heat to it the plastic forms around the bottle, circuit and sensor. In both options the medication label will then be placed over either the neoprene sleeve or shrink sleeve.

Problems and Possible Resolutions

When miniaturizing the circuit to a printed circuit board we have to make sure that we allow enough space for each part to rest without touching any other part. Our goal is to produce a printed circuit board with 1 cm x 1 cm dimensions. If we cannot accomplish the soldering ourselves we will then have to contact a company to do it. Our client's requirement is that we deliver 10 working bottles at the end of the semester and with a working budget of $1,000 to start; having a company do the soldering is not totally out of the question.

An additional problem we may encounter is in disguising the magnet located on the bottle cap as well as making sure the Hall sensor is within range of the magnet. As of now our plans on how to disguise the magnet remain unresolved. The Hall sensor, however, will be disguised beneath the neoprene or shrink sleeve.

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Ophthalmic Dose Compliance Monitor
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Function: Our objective is to develop and miniaturize a dose compliance monitor that would record (unknown to the client) when (date and time) a topical ophthalmic medication was delivered. There are currently older designs of compliance monitors designed for ophthalmic medications, but our design should be a cost effective improved model. Ideally we would be able to manufacture approximately 10 of these devices for use in studies. It could be as simple as some of the older models that recorded when the top of the bottle was removed and the bottle inverted. Maintenance of sterility of the medication is imperative.

Client requirements: Our client's requirements are as follows -

- Minimize the size of the circuit in order to discretely place on eye dropper bottle
- Device must be placed on the outside of the bottle
- Device must record date and time of each application

Design requirements:

1. Physical and Operational Characteristics

a. *Performance requirements*: The device will be used daily based on prescription. It must be able to store each application's information for up to six weeks.

b. *Safety*: In order to prevent contamination of the medication, the device must be applied to the outside of the bottle without opening the cap.

c. *Accuracy and Reliability*: The device must record information only when the medication is used and not when it is simply moved from one place to another.

d. *Life in Service*: Our device should be sustainable with every day use for a duration of up to six weeks.

e. *Ergonomics*: The device cannot interfere with the patient's application of eye drops. It must be small enough to fit on the side or bottom of a 2cm diameter bottle. The device must also be unbeknownst to the patient.

f. *Size*: The device must be miniaturized in order to discretely fit on an eye drop bottles of 5-15 mL volumes.

g. *Weight*: Weight will be restricted due to the size.

h. *Materials*: We will be using a circuit or sensor and an insulating sleeve.

2. Production Characteristics

a. *Quantity*: 10

b. *Target Product Cost*: $100/bottle

3. Miscellaneous

a. *Customer*: Any parent or pet owner that will be applying ophthalmic doses to their child or pet.

b. *Patient-related concerns*: There should be no concerns because the patient should not be aware of the device.