Inductive Charging for Medication Adherence Tracking System for Healthcare Provider Feedback

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Abstract: Accurately and efficiently tracking patients' adherence to medication and providing feedback about the management of their medical regimen in real-time is a common problem for healthcare providers today. Doing this for eye drop medication is particularly difficult due to current solutions focusing on regimented adherence to pills, but very rarely to eye drops. Previous work on this issue has been done to create an intelligent bottle sleeve that is capable of detecting eye drop use, measuring fluid level, and forwarding that information to a healthcare team to make informed decisions on treatment or support for the patient. This work is extrapolating on that design by introducing inductive charging to allow the device to be charged wirelessly as well as creating a base station that charges the device and will eventually house electronics for wifi-enabled communication. These additions make the device's overall user experience simple and easy to use by abstracting away the electronic components for a clean, enclosed design.

Keywords: inductive charging; embedded design; glaucoma; internet of things; adherence; user experience

1. Background

Glaucoma is the leading cause of irreversible blindness worldwide and the third leading cause of irreversible blindness in the U.S.[1] and although it is initially asymptomatic, the quality

[1] https://www.preventblindness.org/sites/default/files/national/documents/Future_of_Vision_final_0.pdf

of life of glaucoma patients steeply declines as vision fades which can greatly increase vision related accidents[2]. It has been shown that rigorous adherence to medication regimen has been targeted as a key change that will improve outcomes for people with glaucoma[3]. Due to this, it is essential to create a device that will allow medical professionals monitor and intervene in patients medication regimens. Because there is currently no standard methods for tracking medication adherence for liquid systems, Nolan Payne and Rahul Gangwani worked to create a smart eye dropper sleeve that could be used to both track and transmit medical regimen data from glaucoma patients to healthcare professionals.

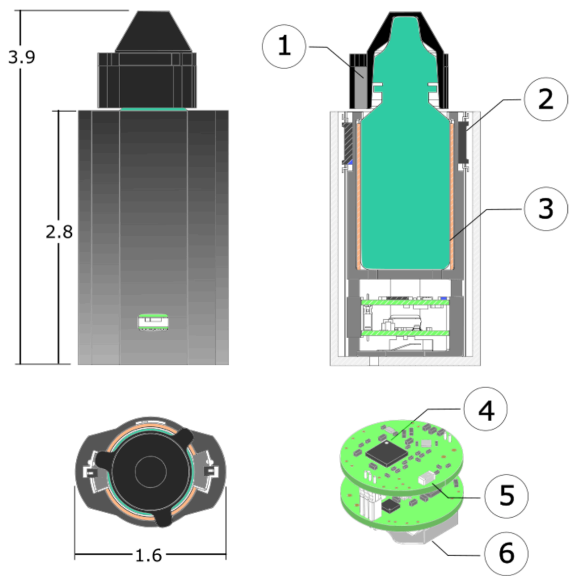

Figure 1: Eyedropper Sleeve Overview

This device was created to be a both compact and portable sensor system that houses a standard eye drop medication package. It employs a sturdy interior skeleton to house a small PCB (4-6) as well as external sensors that are used to sense different use cases. The electrical components as well as the skeleton are then covered in a flexible sleeve. The device contains both onboard and external sensors that are used in parallel to sense when the eye dropper medication is being used as well as the amount of liquid that has been dispensed. It uses reed switches (2) to detect cap placement, IMUs to detect absolute orientation of the bottle as well as an external capacitive sensor (3) to determine the precise liquid level inside of the bottle. Finally, an on board bluetooth stack is able to communicate with a wifi enabled base station in order to update healthcare professionals in real time.

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[2] https://www.mdpi.com/1424-8220/20/8/2435

[3] https://www.mdpi.com/1424-8220/20/8/2435

At the conclusion of Nolan and Rahul's work, the device was able to identify 97% of use cases of the device, measure the fluid level inside of the bottle at a 0.4mL resolution and effectively transmit data wirelessly to healthcare providers. This device was also able to operate for 7 hours unattended due to its low power aspects.

2. Project Objectives

Because the device could now accurately perform its intended functions, making it easy to use and friendly to the user was imperative to producing a system that would be used by a target population that trended on the older side. This work elaborates on Nolan and Rahul's design by enclosing the entirety of the electronics inside of the flexible sleeve while simultaneously introducing inductive charging into the sleeve itself as well as creating a charging base station for the device that could house both the charging hardware as well as the wifi enabled base station that enabled communication with healthcare providers.

The goals of this work were twofold with one side consisting of understanding and elaborating on the embedded system while the other was adapting the mechanical design of the sleeve as well as designing a charging base station for the bottle to sit on. On the electrical side, understanding the basics of inductive charging was imperative to making an informed choice to fit the current charging needs of the device. A comprehensive knowledge of the current charging system was also necessary. These will be discussed in detail later. Mechanically, the eye dropper sleeve needed to be adapted not only to house new charging hardware, but also needed to be altered in a way that would maximize the charging characteristics of the inductive charger. Finally, a base station needed to be designed and manufactured that would efficiently house and charge the eye dropper sleeve.

3. Approach

3.1 Inductive Charging

Inductive charging is a wireless charging protocol that works by a coil (denoted the transmission coil) receiving an AC excitation that generates a current through it. This, in turn, generates a magnetic field around the coil that is able to induce a current on a second coil (denoted receiver coil). The amount of current induced on the receiver coil is a main consideration in inductive charging and is proportional the the flux passing through it. This is known as an "open-loop" configuration and, while it does work, it is generally inefficient and wasteful due to a large amount of power being lost to heat[4].

[4] https://www.electronicdesign.com/power-management/article/21800823/electromagnetic-induction-the-basic-principle-behind-wireless-power

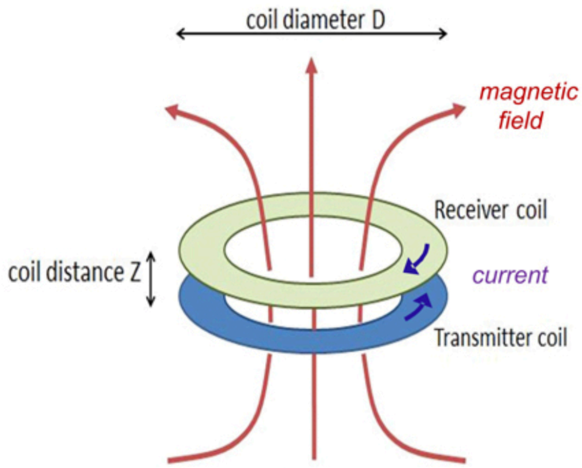

Figure 2: Open-Loop Charging Configuration[5]

A more practical and efficient configuration, illustrated in Figure 3, is a closely coupled, intelligent wireless power system. This configuration transfers power in the same way as the open loop system, but uses additional hardware to control power output from the transmitter side. The RX and TX integrated circuits communicate between each other to respectfully request and deliver the necessary load current. This communication can occur in different ways, but is generally separated into "in band" communication where the devices talk through the inductive coupling while out of band communication refers to devices that communicate using other wireless protocols like Bluetooth.

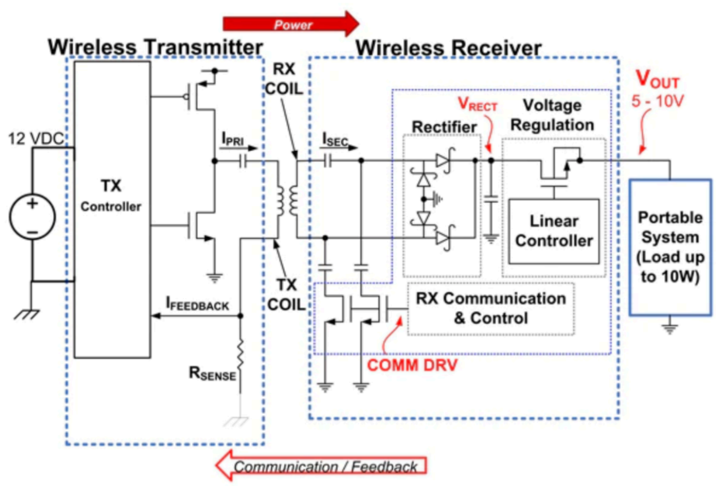

Figure 3: Smart Inductive Charging[6]

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[5] https://www.electronicdesign.com/power-management/article/21800823/electromagnetic-induction-the-basic-principle-behind-wireless-power

[6] https://www.electronicdesign.com/power-management/article/21800823/electromagnetic-induction-the-basic-principle-behind-wireless-power

Outside of the innate characteristics of the charger, in order to maximize this current flow on the receiver side, there are three main considerations that must be taken into account. First, it is imperative that the coils are aligned correctly. Ensuring that the transmission coil and receiver coil are directly above and below each other will maximize the flux passing through the receiver coil, thus maximizing the induced current. The proximity between the two coils will also have a drastic effect on the flux, and similarity the induced current. Finally, shielding around the coils is important to protect other circuits from being affected by the magnetic field.

3.2 System Analysis

After understanding the basics of inductive charging, the current eye dropper system had to be analyzed for its charging characteristics. The original system was charged via MicroUSB which delivers approximately 1A with a 5V differential[7]. The PCB was also mounted with a MCP73831 power management integrated circuit which was configured to deliver 14.5 mA to the battery during a charging phase as well as being able to shunt that current when the battery had been fully charged. Because of this power management circuit, the characteristics of the inductive charger did not have to completely match those of the USB charger. From this system analysis, it was clear that the inductive charging unit had to deliver 5 Volts as well as a minimum of 100mA of current to the PMIC.

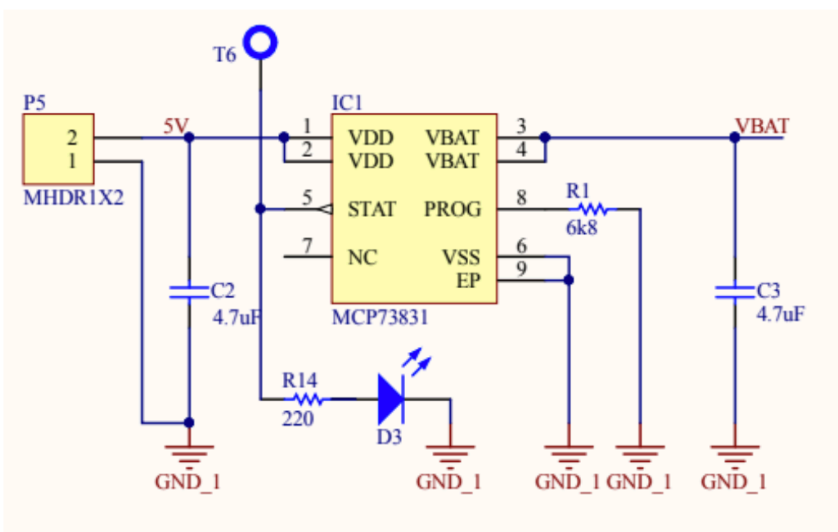

Figure 4: On Board Power Management Circuit

[7] https://www.extremetech.com/computing/115251-how-usb-charging-works-or-how-to-avoid-blowing-up-your-smartphone

3.3 Inductive Charging Options

Using the information from the system analysis, a choice had to be made between creating another PCB to add to the existing stack, or to use a pre-manufactured, inductive charging development kit to test and verify the system. Due to the moderately long lead time of modifying, ordering and assembling PCBs, the development kit choice was used. Inductive charger development kits were inspected for functionality, size as well as cost and two specific kits were closely examined: the STEVAL-ISB68WA shown in Figure 5 and the DFRobot Wireless Charging Module shown in Figure 6.

The STEVAL-ISB68WA was the most versatile dev kit examined in that it was a 5 volt 2.5 watt output receiving unit that was compliant with Qui standards, meaning it could be used with any Qui compliant charging module. It also fit the mechanical design constraints in that it was only 10mm x 10mm meaning that it would fit easily into the existing sleeve design with only slight modifications. This module also came with a 400 kHz I2C interface for communication with a host system for simple debugging. Although this option fit all of the electrical and mechanical specifications, due to its moderately high price as well as sourcing issues, this development kit was not chosen.

Figure 5: STEVAL-ISB68WA Development Board

The DFRobot Wireless charging module offered suitable electrical characteristics as well in that the receiving module was able to output 5 volts and a maximum of 300 milli Amps of current. This development kit also included its own transmitter coil that would be able to be seamlessly integrated into a custom base station unit. Mechanically, this kit was slightly less optimal than the STEVAL-ISB68WA due to its elongated PCB on the receiver module. Nonetheless, it ended up being a cheap and easily obtainable kit that fit the necessary design constraints.

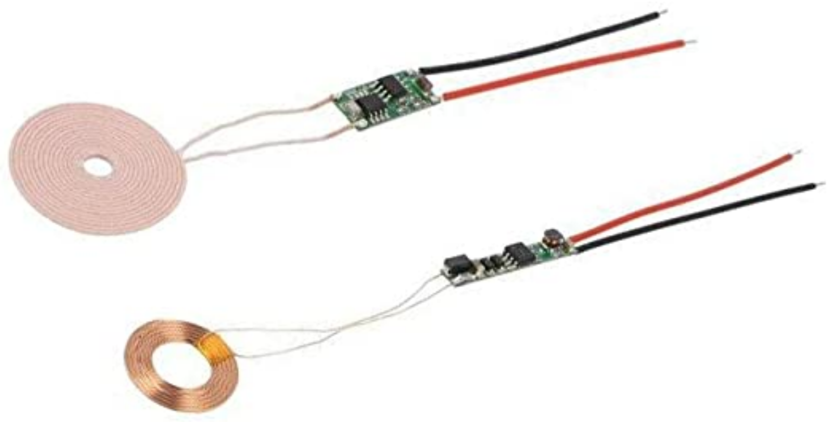

Figure 6: DFRobot Wireless Charging Kit

4. Results

4.1 Electrical

After receiving the development kit, it was imperative to test the charging characteristics of the transmitter and receiver coil against the microUSB. This test was performed using two of the three characteristics mentioned in section 3.1: alignment and proximity. While keeping the alignment fixed, and changing the proximity of the two coils between a variety of distances, the optimal charging zone was found to be between 0 and 5mm.

Table 1: Inductive Charging Proximity vs Voltage (V) and Current (mA)

	Proximity (mm)	Voltage (V)	Current (mA)
USB	N/A	5.04	3.65
Inductive Charger	0	4.96	3.57
	2	4.96	3.50
	5	4.96	3.50
	10	3.85	2.65
	15	2.18	1.74
	>15	0.00	0.00

4.2 Mechanical

The proximity testing offered another mechanical design constraint that had to be taken into account for the sleeve and base station interaction. This showed that the material between the transmission coil and receiver coil could be no more than 5mm. The engineering drawing shown in Figure 7 illustrates the solution to each of the mechanical design constraints discussed in sections before this.

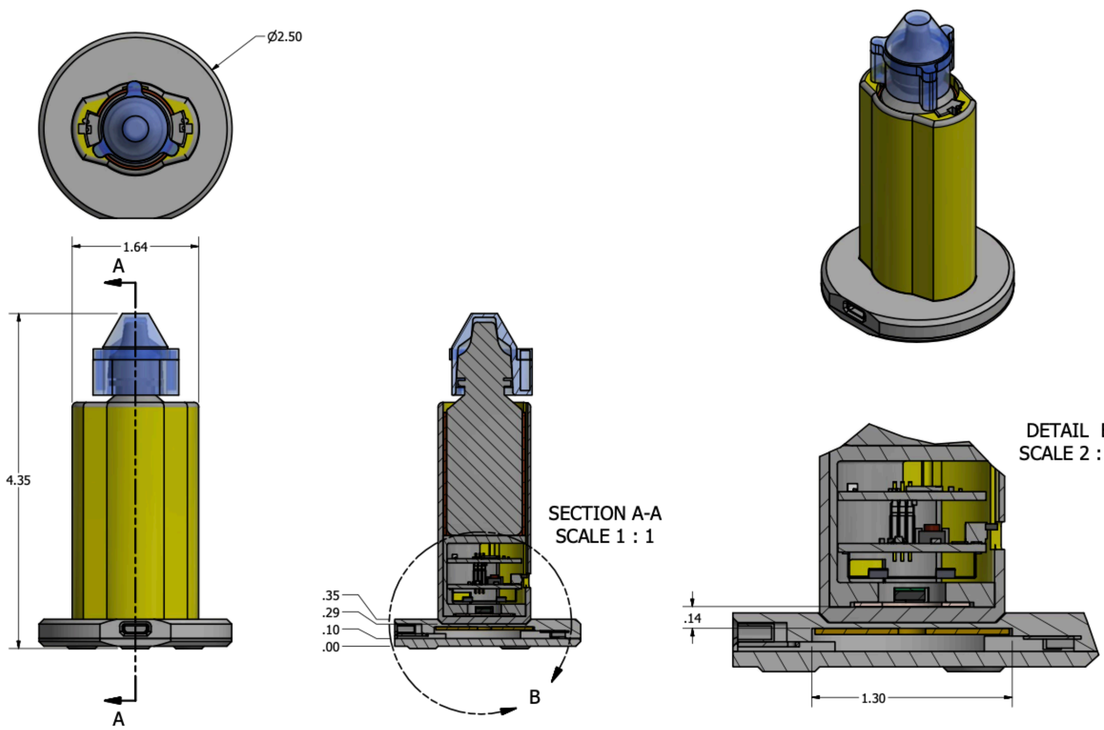

Figure 7: Revised Sleeve Design and Charging Base Station

Although theoretically each of the components fit snugly inside the sleeve and charger, the actual manufactured product proved otherwise. Although it was a good start, revision is needed to ensure each component as well as wires and coils fit inside of the case and base station comfortably.

5. Conclusion

This work concluded with an electrical system that could charge the eye dropper device wirelessly through inductive charging. Mechanically, the first manufactured iteration of the adapted sleeve design as well as the charging base station highlighted changes that needed to be made to comfortably and securely fit all electrical components. Because of this, there are many next steps that can be taken with this project including but not limited to: updating the mechanical design, power and battery analysis, and user experience testing.