

# **Design of a Device to Help Severely Mentally Ill Patients Quit Smoking**

## Mid-semester Report



BME 200/300

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## 1.0 Introduction

### 1.1 Background

Our client for this project is Dr. David Gustafson, an emeritus research professor of Industrial and Systems Engineering, director of the Center for Health Enhancement Systems Studies at the University of Wisconsin-Madison and his colleagues from Dartmouth College, Dr. Mary Brunnette (MD), an associate professor of psychiatry, and Dr. Joelle Ferron, an assistant professor of psychiatry.

A major issue with mental health patients that is often improperly acknowledged is tobacco and/or drug addiction. The rate of cigarette smoking is much higher among people with severe mental illnesses than that of the general populace (3); 45%–90% in the severely mentally ill (SMI) as opposed to only 20% in the general populace (2). According to Dr. Ferron “approximately three-quarters of people with severe mental illnesses smoke cigarettes”(3). Bridget Grant from the National Institutes of Health conducted a study to view the correlation between SMI (defined as *DSM-IV* Axis I and II disorders) and nicotine addiction. In an assessment of 43,093 subjects through face-to-face interviews, Grant determined that individuals with comorbid addiction and mental illness consume a large percentage of the total cigarettes consumed by the smoking population (5). This statistic shows that cigarette addiction is not only more prevalent in the SMI but it is also a more serious problem in this group.

Smoking cigarettes causes 87 percent of lung cancer deaths, and causes other forms of cancers and health problems, including lung disease, heart and blood vessel disease, stroke and cataracts (8). Higher rates of smoking in mentally ill people lead to particularly high rates of diseases caused by smoking, resulting in shorter life expectancy in this population (8). There is little doubt that smoking has many adverse impacts on one’s health and that this problem is particularly prevalent in mentally ill people.

Quitting smoking is very difficult due to the strong psychological and physical additions this habit creates. In the population of smokers who do not quit, nearly half will die of smoking-related problems. After quitting smoking, circulation begins to improve, and blood pressure starts to return to a normal, lower state. Short-term problems such as anxiety or irritability can occur when one tries to quit smoking (8). It is common for smokers to attempt to quit more than once and often to seek aid in the form of professional counseling and quitting programs because of the level of addiction smoking creates. The difficulty of quitting can be exacerbated by mental illness.

Meanwhile, Dr. Ferron conducted an 11-year study in which followed 174 individuals with mental illness and co-occurring substance abuse issues. 89% were smokers at the initiation of the study and 11 years later only 17% were not

smoking. One particularly interesting note is that the sample did not use evidence proved methods to help quit including nicotine replacement and bupropion (3). This suggests that these treatments are inaccessible or unwelcome to the SMI (at least in individuals with co-occurring substance abuse problems).

Since smokers with severe mental illnesses often do not use traditional additional resources (to quit smoking), additional help and guidance may be necessary to aid these patients in quitting process. It has been determined that this disconnect between SMI smokers and traditional quit smoking resources is due to lack of interest (6,7), an inability to access resources (9) or other unknown reasons. Research shows that a tailored program for the mentally ill (designed and tested with the needs of the SMI in mind) struggling with addiction can improve the odds for individuals trying to quit (1,2).

In order to develop additional quitting resources, one needs to understand which resources are not used and why. Dr. Brunette also conducted survey of websites dedicated to providing help quitting smoking (1). A team of five experts measured the usefulness (based on content) and usability of the first four hits from a Google search for quitting smoking. These sites were then presented to 16 SMI smokers who were observed and interviewed on the experience. A website that was navigable by the subjects was rated as lacking in content by the experts. One site that was rated highly by the experts in both categories was inaccessible to the subjects because they could not navigate the site to find information the experts had deemed essential in quit attempts. These results demonstrate that the SMI smokers may not take advantage of quitting resources because they cannot access them. In addition, it shows that what may seem accessible to experts is not necessarily accessible for the SMI smokers.

The prevalence of smoking in SMI smokers in conjunction with the inaccessibility of resources to this population calls for a more tailored quitting system. This system should be built from the results of the previous studies; e.g., Dr. Brunette's computer cessation aid. The system would be designed with information about how SMI individuals interpret information and be targeted toward reaching this under supported audience. The final goal would be to have a comprehensive program that assists SMI smokers in quitting ideally through constant (24 hours a day) monitoring and accessible information. A large gap in the research on this topic is why SMI people, in particular, turn to smoking and often develop addictions more than other members of the general populace. Several studies found that SMI people can use structured computer programs to aid in quitting process (4). Additional research should be done to evaluate the usefulness of this type of additional treatment specific to the SMI smokers to help with quit smoking.

## **1.2 Problem Statement**

To design a case for holding cigarettes that is augmented to specifically help people with severe mentally illness(SMI) quit smoking. This case is called the Pack Pal. The case will house a sensor to detect if the user attempts to open the case, another sensor to detect whether the case was actually opened and a third sensor will be used to detect how many cigarettes were removed from the case. The data from access attempts will be continuously transmitted to the smartphone wirelessly. The data will be transmitted to the phone via bluetooth (v4.0) as serial characters coding for various responses to sensors. For example, the character 'a', would represent access to the case. The phone will detect access attempts, opening and closing. Each time the user accesses the case, the phone application will ask the user a series of questions about their desire to smoke, the environmental or emotional cue that prompted the urge, and to rate the salience of the urge. Overtime, the user will gain knowledge about their own use and will then be able to use skills (aquired via the application) to cope with not having a cigarette. One of these skills could be to do something else (play a video game, listen to music or do another activity the participant has indicated helps them avoid smoking) or remind them of the reasons that they want to quit (display a picture of their child, pet or loved one). In addition, the application will send daily updates to the subject and/or to any clinician or provider the subject specifies.

## **1.3 Motivation**

Research shows that SMI patients want to quit smoking. There are many useful quitting programs available for the general population, but there are no programs designed specifically for SMI patients. The Pack Pal acts as a coach for the user and also collects important data that aids the user in reaching their goals. A trip to Chicago is planned in order to interact with SMI patients to gain a better understanding of how to tailor the Pack Pal to their needs.

## **2.0 Design Specifications**

### **2.1 Case Requirements**

The case needs to stay locked until the user attempts to open the case, wherein the case will stay locked for a specific time delay before opening. The case also needs to sense three things: when the case is attempted to open, when the case actually opens, and the number of cigarettes that are removed from the case. Finally, the case will transmit its data to the smartphone wirelessly.

### **2.2 Smartphone Requirements**

The smartphone needs to analyze the data from the case. When the user attempts to smoke a cigarette, the smartphone needs to display countermeasures to

discourage the smoking behavior. The phone could display a picture of a diseased lung, call family or friends for a distraction, or use social media for support. The phone will also record what triggered the urge to smoke and rate the craving of the cigarette. The user will also be able to access weekly updates on how many cigarettes they have smoked that week to compare with other weeks.

### 3.0 Design Options and Alternatives

In order to meet the product design specifications, many design options were brainstormed and considered. Each aspect of the project had multiple routes for implementation, and each option had to be carefully analyzed. For the case, there were three main design aspects: sensing the presence of a cigarette, battery/power and the locking mechanism.

#### 3.1 Cigarette Sensing

For the cigarette sensing system, accuracy and consistency of measurement were important factors considered in the brainstorming process. It is necessary to have an accurate reading every time the cigarettes are checked and have this reading be consistent between checking periods. As with any electronic system, power consumption of the cigarette sensing system needs to be taken into account. Also, minimizing the number of components required to implement the circuit is key to fitting the system into the final case.

##### 3.1.1 Separate IR LED and IR Sensor

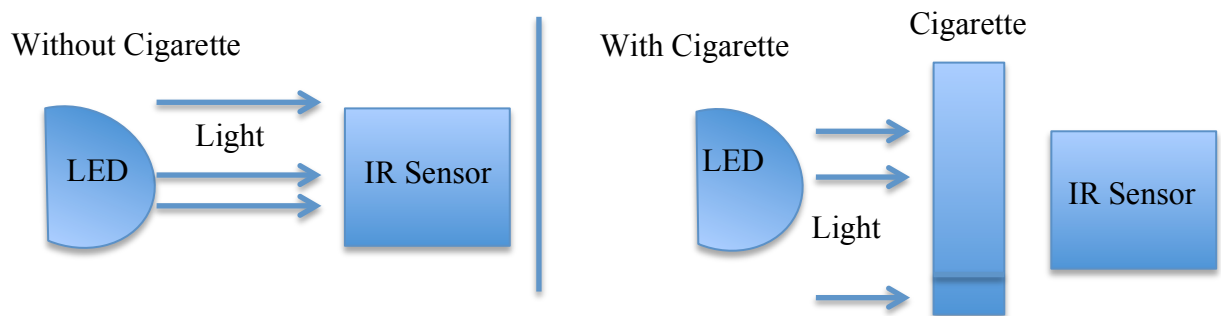


Figure 3.1.1

The first design option was a system dependent on an array of IR LEDs and corresponding sensors for each LED. This system works under the principle of IR transmission. If a cigarette is present, the IR LED light will be blocked and the sensor will not pick up a signal. However, when the cigarette is removed, the IR signal will no longer be blocked and will be picked up by the sensor, which in turn will send a signal to the microcontroller indicating the absence of a cigarette. (Figure 3.1.1)

### 3.1.2 Integrated IR LED and IR Sensor

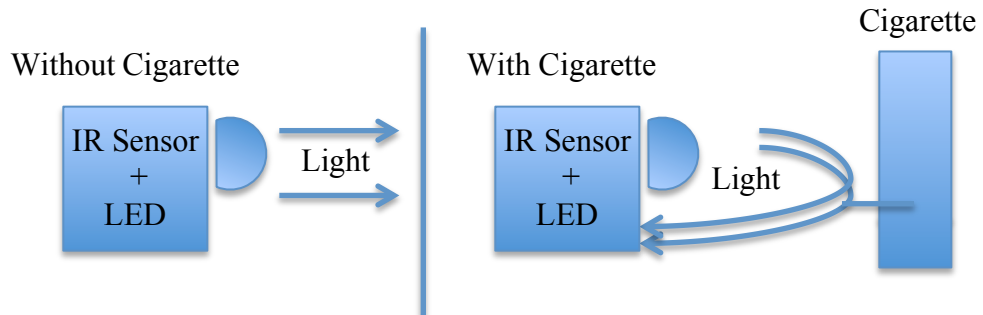


Figure 3.1.2

The second design option was an integrated IR LED and IR sensor system where the two were part of the same unit. This system works under the principles of IR reflection and absorption. Each cigarette would have an accompanying sensor and LED. In the presence of a cigarette, the LED would transmit light that would reflect off of the cigarette, radiating back to the sensor where it can be read. After the removal of a cigarette, the LED would transmit an IR signal that would not be reflected back at the sensor, indicating the absence of a cigarette. (Figure 3.1.2)

### 3.1.3 Flex/Strain sensitive resistor

The last design option was based on the use of a flex or strain sensitive resistor. Each cigarette would have a flex resistor associated with it. When the cigarette is placed in the case, it will put a small amount of strain on the resistor. This strain would cause a change in resistance, which could be amplified and measured by the microcontroller. When the cigarette is removed, the strain on the resistor would be decreased, resulting in a decrease in the corresponding resistor. This change would again be amplified and read as the absence of a cigarette.

## 3.2 Battery/Power

Since this device is a portable electronic device, it will need to be battery powered. Reliability of the battery or batteries is very important for this device as well as the overall efficiency of the system. The battery unit should be cost effective to keep the price per unit at a minimum. Also, it is important to consider the cost imposed on the end user while brainstorming and comparing designs. Lastly, limiting the physical size of the battery unit is key to fitting the whole system into a smaller space.

### **3.2.1 Replaceable Batteries**

A power unit utilizing replaceable batteries is a simple design. It is cost effective for the development and production phase, however it is more expensive for the end user.

### **3.2.2 Removable Lithium-Ion Battery**

The second design option considered was a lithium ion battery with an external charger. For this design the battery would be removed each time the case needed to be charged. It is more expensive for development and production, but would save money for the end user.

### **3.2.3 Wall Charge Lithium-Ion Battery**

The third design option was to utilize a semi-permanent lithium-ion battery. For this option, the battery would always be in the case, only to be accessed if there is an error or the battery has greatly declined in charging performance. A wall-charger could then plug into the case and charge the battery much like a modern day cell phone.

## **3.3 Case Locking Mechanism**

While brainstorming design options for the case locking mechanism, the size of the locking system was one of the largest factors taken into account. Again, this aspect of the design is important because the final design will have to be placed inside of a cigarette case. Also, the physical strength of the lock was a major factor. The case should not be able to be forced open by the patient while in the locked state. Reliability of the locking mechanism was taken into account during the brainstorming process because the user should depend on the lock being locked when it is supposed to be, but more importantly unlocking when triggered. Lastly, the amount of power consumed by the locking system at rest (locked) and active (unlocked) was important in the brainstorming process.

### **3.3.1 Magnetic**

The first design option would include a permanent magnet positioned opposite of a wire coil. When current is run through the coil, a magnetic field oriented opposite to the permanent magnet would develop, holding the case closed through magnetic attraction. When current to the coil is stopped, the case would unlock.



### 3.3.2 Linear Actuator

The second design option would be a custom linear actuator. This design would consist of two small loops positioned on opposite sides of the case. While closed, the two loops would overlap and a small metal rod would slide between them, locking the case. On one end of the rod there would be a magnet surrounded by a wire coil. At rest, the rod would be extended and the case would be locked. When current is applied to the coil a magnetic field opposite of the magnet on the rod would be created, withdrawing the rod from the loops and allowing the case to be opened.

## 4.0 Design Matrices

In each design matrix, the design traits were given different weights based on overall importance to the design. Each design option was then analyzed and given a score between one and ten for each trait. That value was then multiplied by the weight and then all of the scores were summed to produce the cumulative score. The design option with the highest score for each category was chosen as the design to pursue.

### 4.1 Cigarette Sensing Matrix

As with every electronic circuit, power consumption was very important to the design. The number of components and the ease of implementation were considered moderate factors, and reliability of the system was considered the most important. (Figure 4.1.1)

<i>Cigarette Sensing</i>	<b>Separate IR LED/Sensor</b>	<b>Integrated IR LED/Sensor</b>	<b>Flex Resistor</b>
Power Consumption (.6)	3	3	4.2
Components (.4)	0.8	1.6	2
Reliability (.8)	4.8	5.6	0.8
Implementation (.3)	0.9	1.5	2.4
<b>TOTAL</b>	<b>9.5</b>	<b>11.7</b>	<b>9.4</b>

#### 4.2 Battery Matrix

For the battery, initial cost (development and production) and long-term cost (for the end-user) were separated with long-term cost given a slightly higher weight. Ease of implementation was considered the most important aspect of the design, followed closely by convenience. Convenience was defined by the case being operational during the battery replacement/charging period. Lastly interaction was included to rate the amount the case would be handled during the battery replacement/charging period. (Figure 4.2.1)

<b><i>Battery</i></b>	<b>Replaceable Batteries</b>	<b>Removable Li</b>	<b>Wall-Charge Li</b>
Initial Cost (.3)	2.1	0.9	0.9
Long-term Cost (.4)	0.8	3.2	3.2
Interaction (.2)	0.4	0.4	1.6
Convenience (.5)	2	1	3.5
Implementation (.6)	3.6	3.6	2.4
<b>TOTAL</b>	<b>8.9</b>	<b>9.1</b>	<b>11.6</b>

#### 4.3 Locking Mechanism Matrix

Power consumption, followed closely by physical strength of the lock were considered the most important traits of the locking mechanism. Ease of implementation was a moderate consideration and the cost of the design was taken into account as well. (Figure 4.3.1)

<b><i>Locking Mechanism</i></b>	<b>Magnetic</b>	<b>Linear Actuator</b>
Power(.7)	1.4	3.5
Cost (.3)	1.5	1.2
Strength (.6)	2.4	4.2
Implementation (.5)	1.5	2
<b>TOTAL</b>	<b>6.8</b>	<b>10.9</b>

## **5.0 Final Design**

The Final design of the Pack Pal system must integrate the circuit with all the aforementioned sensors, indicators and other components into a handheld case. A preliminary SolidWorks model of the system can be seen in figure 8.3A in the Appendix section. The circuit will also contain several components to accomplish the design specifications including sensors, indicators, buttons and the Bluetooth module. The integrated IR/LED sensors will be used to sense the number of cigarettes in the case. In addition, there will be two LED indicators; one to indicate whether the case is unlocked and another to indicate the power level of the semi-permanent Lithium ion battery.

All of these components will be controlled via the microcontroller, which will gather the data from each access attempt and trigger the Bluetooth module to send this data to the phone. The system will be powered via a wall chargeable Lithium ion battery. The case will lock via a linear actuator mechanism. The phone application will log data, analyze, and display it for the user and support contacts. The final design of the Pack Pal system will have to integrate all aspects of this design into a usable case and accompanying smartphone application. Figure 8.5 A in the appendix section shows how all the aspects of the system will interact.

### **5.1 Cigarette Sensing**

The sensing of how many cigarettes are in the case will be accomplished via an array of IR LED sensors. These sensors are components called the QRD114 and are a combined infrared LED and phototransistor. For more information on this component please see appendix 8.1.

### **5.2 Battery**

This battery must be able to last about eight hours providing normal operating conditions for the Pack Pal system. This battery will be a semi-permanent lithium ion battery that will accommodate wall charging and removal from the case for ease of use.

### **5.3 Locking Mechanism**

The locking of the case will be accomplished by a linear actuator. The actuator will be (under normal operating conditions) slid into two overlapping loops from the bottom and top of the case effectively preventing the case from being opened. Upon a signal (press of push button to open case) a timer will commence and after a specified time delay the actuator will retract from these two loops and the case will be unlocked.

### **5.4 Application**

The smart phone application will be developed for Android phones and will be specifically tailored for SMI patients. The phone application will then take data (including if the case was accessed, opened and if any cigarettes were taken) and format it. This formatting will have one report to send to the healthcare professional involved in the quit attempt and will have all of the raw data to use as best suits their needs. In addition, data will be formatted in an easily accessible and understandable manner for the user so they can view their progress throughout the attempt. A software block diagram (see Appendix 8.5B) displays how all the aspects of the application will interact. The main view of the is the preliminary user interface of the application and the other aspects of the block diagram will be accessible from this interface.

## **6.0 Future Work**

### **6.1 Case Design**

The physical layout and design of the circuit still need to be established. In the development of this design it will be important to consider the particular needs of the users (SMI patients). This design will have fit up to 20 cigarettes and the electronics of the circuit.

### **6.2 Electronics**

The first step in the design of the circuit is to complete a fully functional breadboard circuit that accomplished all the goals specified above (see section 2.0 for design specifications). Then assessments of power requirements can be made on this circuit to determine the type of battery to power all components. This circuit can be make more permanent on a wire wrapped board to establish a more concrete product. Finally after testing the circuit for functionality and power behavior (battery life etc.) it can be sent for printed circuit board (PCB) printing. This PCB version of the circuit will be much smaller and can be fitted inside the completed case.

### **6.3 Application**

The mobile application must be developed based on specifications from our client and from our design specifications above (section 2.0).

## 7.0 References

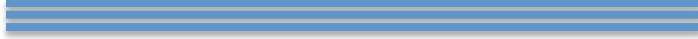
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## Appendix 8.1

Integrated IR LED Sensor QRD 1114

### **Emitter**

Maximum Forward Voltage: 1.7V  
Maximum Reverse Voltage: 5V  
Maximum Reverse Current: 100  $\mu$ A



### **Sensor**

Dark Current: 100 nA

## Appendix 8.2

### ***Design of a Device to Help Severely Mentally Ill Patients Quit Smoking*** **Product Design Specifications**

Client: Prof. Gustafson, Prof. Ferron, Prof. Brunette

Advisor: Dr. Nimunkar

Team:

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Date: October 21, 2012

#### **Problem Statement**

To design a case for holding cigarettes that is augmented to specifically help people with severe mentally illness(SMI) quit smoking. The case will house a sensor to detect if the user attempts to open the case, another sensor to detect whether the case was actually opened and a third sensor will be used to detect how many cigarettes were removed from the case. The data from access attempts will be continuously transmitted to the smartphone wirelessly. The data will be transmitted to the phone via bluetooth (v4.0) as serial characters coding for various responses to sensors. For example, the character 'a', would represent access to the case. The phone will detect access attempts, opening and closing. Each time the user accesses the case, the phone application will ask the user a series of questions about their desire to smoke, the environmental or emotional cue that prompted the urge, and to rate the salience of the urge. Overtime, the user will gain knowledge about their own use and will then be able to use skills (aquired via the application) to cope with not having a cigarette. One of these skills could be to do something else (play a video game, listen to music or do another activity the participant has indicated helps them avoid smoking) or remind them of the reasons that they want to quit (display a picture of their child, pet or loved one). In addition, the application will send daily updates to the subject and/or to any clinician or provider the subject specifies.

#### **1. Client Requirements**

- The case should be difficult to break and hold at least 20 cigarettes (should be modeled after the cases in current use).
- The case should have an onboard rechargeable battery.
- The case should unlock after a request from the participant via a push button after a specified time delay. Then the case will send this information to the cell phone application via Bluetooth.

- The system should interact (can be through phone) with the user to help track behaviors, beliefs, and urges around smoking and support coping skills. The electronic pack should lock for a time delay specified by research on SMI patients who smoke. While the case is locked the subject is to engage in coping skills to delay and reduce smoking.
- The device and the application should be easy to use, with simple opening/closing mechanism, uncluttered interface on phone, simple text, minimal layers of navigation, minimal requirements for abstract thinking and memory.
- We should have a working prototype (five copies) done in Spring 2013.

## **2. Design requirements**

### **2.1 Physical and Operational Characteristics**

a. *Performance requirements:*

The device is required to be augmented for daily and frequent use. Severely mentally ill patients may attempt to access it in different time delays that vary from few minutes or sometimes few seconds in the case of severe addiction to few hours in less severe cases.

b. *Safety:*

The cigarette case should be developed for mentally ill patients so it should be totally safe and free of warnings because we cannot rely on the patient to take precautions.

c. *Accuracy and Reliability:*

The case should record and send reliable data about the access times the opening of the case and the number of cigarettes taken because this information can lead to faulty interpretations if it lacks accuracy. For example if the open button is pressed but the patient did not open the case because he controlled his urge but the data collected showed that the case was opened this will affect the treatment.

d. *Life in Service:*

This case should serve the patient for the whole period of the treatment and remain useful after the treatment is done for future uses. It should work in different countries and operate 24/7 but the battery needs to be recharged every 8 hours.

e. *Shelf Life:*

The battery that is included in the case should be a rechargeable battery for efficiency and ease of use and also because it is more environmentally friendly.

f. *Operating Environment:*

The cigarette case must adapt to different working environments. It can be exposed to different temperatures and different humidity ranges. It can also be exposed to dust, vibrations and accidental hits. We have to make sure that the accuracy of the data is not affected by those factors.



## **2.2 Production Characteristics**

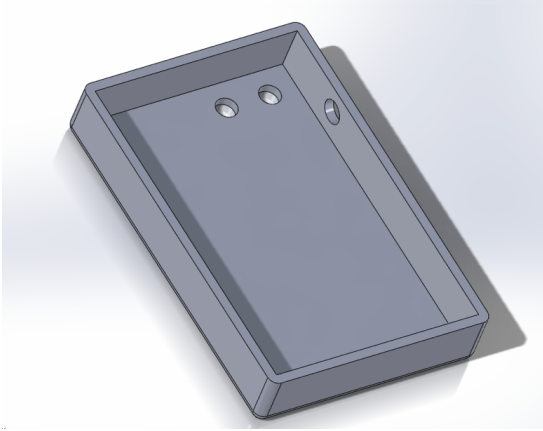
- a. *Quantity:*  
We should have five devices for the research purpose.
- b. *Target Product Cost:*  
The cost of this cigarette case will be higher than the cost of a normal cigarette case but it has to be a feasible price not above 100\$. The case will be purchased once only and it can be refilled with cigarettes so this is an initial cost only.

## **2.3 Miscellaneous**

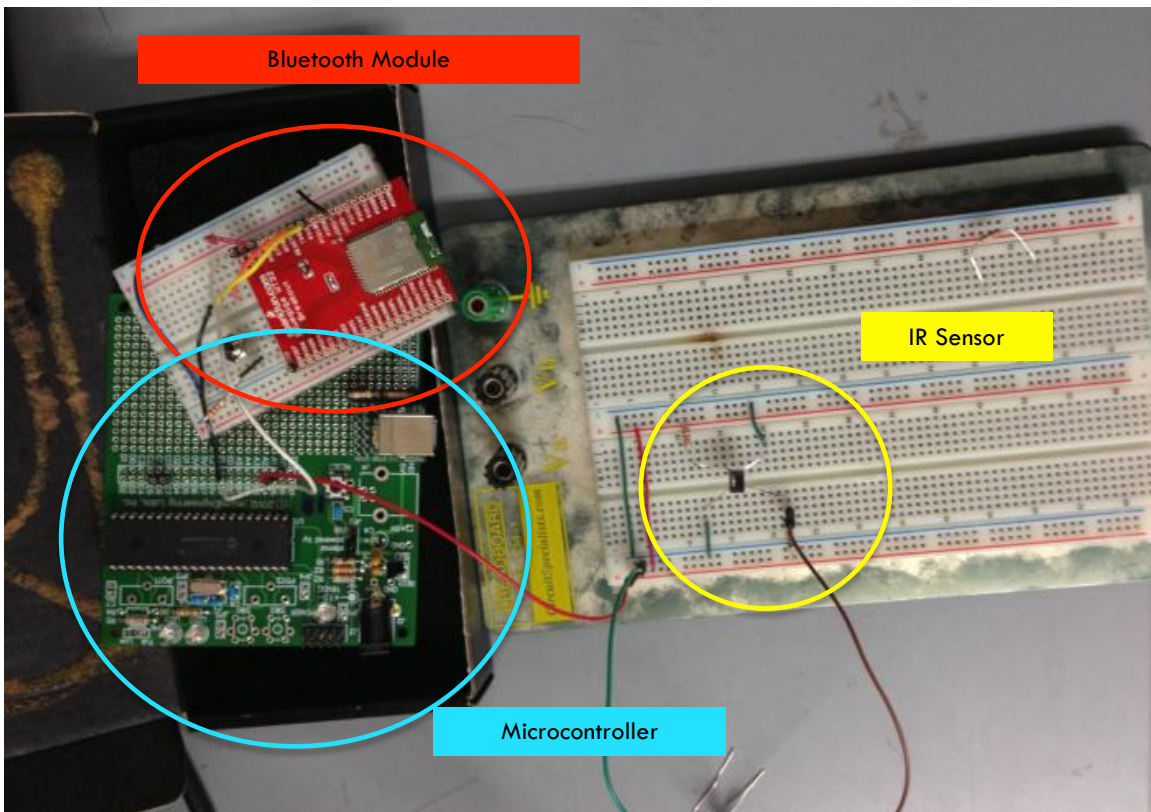
- a. *Patient-related concerns:*  
The patients we are dealing with are mentally ill patients so extra considerations should be taken into account regarding the system so it is tailored to the needs of the users. The collected data should be confidential and provided only to a specified mentor, clinician and a system administrator.

### Appendix 8.3

Figure 8.3 A

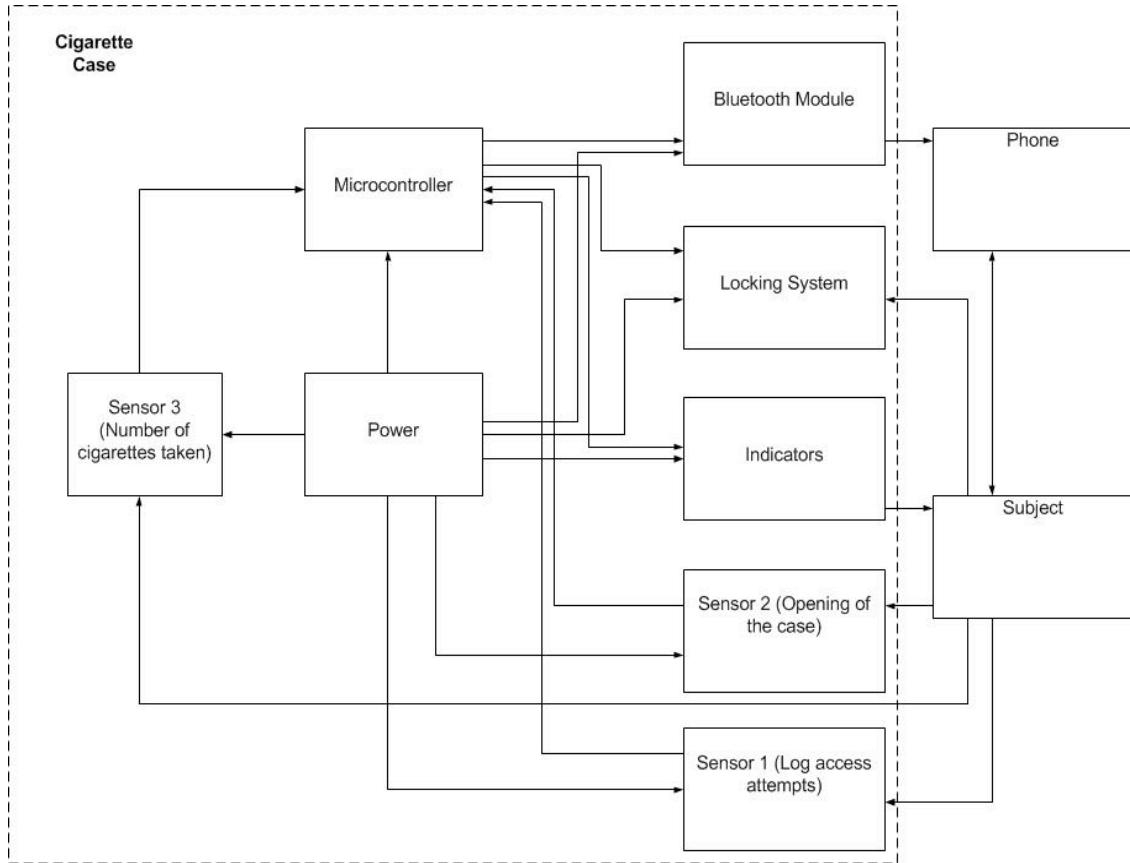


### Appendix 8.4 Breadboard Circuit

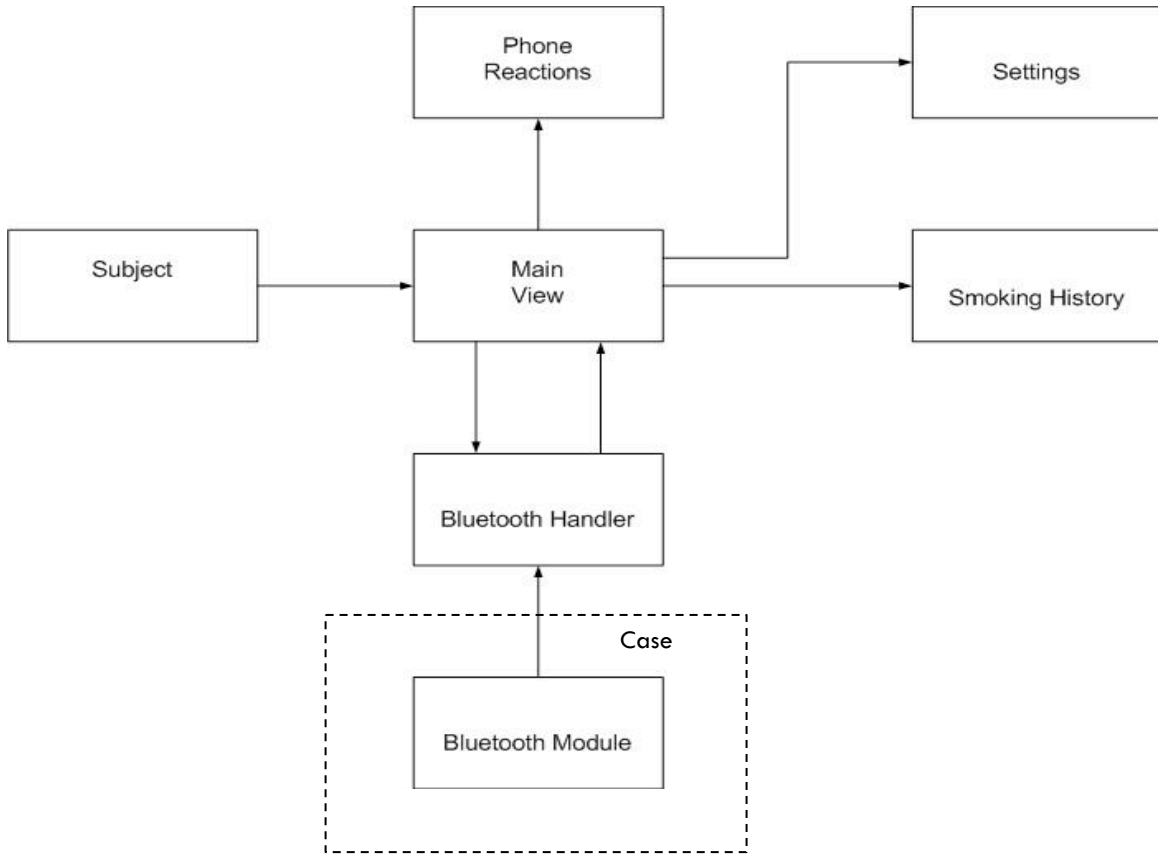


## Appendix 8.5 Block Diagrams

### 8.5A Hardware Block Diagram



### 8.5B Software Block Diagram



## Appendix 8.6 Preliminary schematic of the circuit with only one IR LED sensor

