Internet of Things
Developing an optimal wireless power transfer system for a real-world low power LED wristband application

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1 Introduction

Although wireless power transfer systems are already widely applied in stationary household equipment, current research offers a tremendous amount of possibilities that can change our perception of energy usage. In an ideal world we would no longer have to concern about wires and depleting batteries. A collection of wireless power transmitters would be able to charge all our products wirelessly, enabling a completely mobile and energy independent workspace or living environment. This report will introduce a reusable mobile real-world low power application that utilizes a wireless power transfer system to eliminate the need for changing batteries. Introducing wireless power transfer techniques into the world of reusable high quality products will greatly reduce the environmental risks of the product and thus increase product value.

In this report we will briefly discuss our choosen paper [1] and present a working product that extends the basic ideas discussed in the paper. As the paper itself did not discuss any *Internet of Things* aspects to their idea, we present a scenario where both techniques could be fully utilized. The concurring product to match this scenario is based on the *Drome Surround light* [9]. The drome is a LED wristband powered by a battery to be worn at concerts that enriches the involvement of the audience by including them into a lightshow and can run for 5 hours after it is switched on. The dromes can be reused after each show by replacing the batteries and this report will focus on eliminating this need. First we will focus on the choosen paper in Section 2 and some prior knowledge in Section 3. Section 4 will discussed our start-up based idea in a scenario, initial wireless transfer system, a state analysis and the concurring protocols. Section 5 will go deeper into the system design by analyzing our electonic model, model the battery life, charging profile and the charge to discharge ratio. In Section 6 the proposed final system design and the internet of things will be discussed. We will conclude our results in Section 7 and present the conclusion and future works in Section 8 and 9.

2 Related work

The assigned paper [1] presents an *"Architectural analysis for wirelessly powered computing platforms"*. As we already discussed the downfalls of the paper thoroughly in class we will not go into too much details, but just present in what ways we extended the proposed idea in the paper. The authors of the paper provide a model for a single kind of wireless powered system. However, the system only assumes power requirements that include constant voltage levels and does not include anything about constant current or power. Furthermore each wireless power packet is assumed to carry constant power and is recieved periodically while the period is known in advance.

In our wireless powered system, the system components differ immensly from the system proposed in the paper. The system in the related work does not include any storage device apart from the small rectifying capacitor, which makes the system useless in the absence of wireless power. For this reason we included a supercapacitor and a battery as the two main big storage components which can keep the system operational even in the absence of wireless power. Also, the related work made some unrealistic assumptions of the periodic reception of constant powered wireless energy packets which led us to make a completely different analytical model as disccused in Section 5. Consequently the related work only provides an intial guideline for wireless powered system, for more practical systems a completely new analytical model is required.

3 Prior knowledge

Because of technolological advancements in materials, the gap between *supercapacitors* and the conventional *batteries* for large charge storage is reducing. Supercapacitors can charge really fast and have a much longer cycle life compared to batteries. Hence supercapacitors are increasing in importance and are slowly becoming a competitor to batteries. However, supercapacitors can hold about 10 times less energy than a Li-ion battery of the same size. The table below gives an overview of the important aspects of the supercapacitor and the battery we took into account during this project. As performance is always a trade-off we ended up combining a supercapacitor with a battery as will be discussed more into detail in Section 5.

Characteristic	Supercapacitor	Li-ion Battery
Charge time	110 seconds	1060 minutes
Cycle life	1 million or 30,000h	500 and higher
Cell voltage	2.3 to 2.75 Volts	3.6 to 3.7 Volts
Cost per Wh	Cost per Wh	0.50−1.00 (large system)

Table 1. Comparison between a supercapacitor and a battery [10]

4 Description of the idea

The idea for our project was to utilize a wireless power transfer system to eliminate the need for changing batteries. However as the scenario depicted in Section 4.1 will display, the charging should happen in a quick and intuitive manner. In this section we will discuss different scenarios, use state diagrams to visually design and discover internal logic of the system and we will introduce some protocols that can handle the system logic.

4.1 Scenario

To create a thourough understanding of our system we developed some scenarios in UML in which the product will be used. These scenarios helped us develop state diagrams to understand the internal states of the product so that we could determine protocols to in turn develop an efficient charge-discharge protocol. The actors in the system are the user wearing the wristband, other users that the user can interact with and the system will be portrayed by the energy bars, energy checkpoints and an online server. The scenarios are portrayed from the perspective of a central user. The perspectives of the energy bar and checkpoint are considerable less complex and follow the perspective of the central user intuitively. The main scenario in terms of natural language is a user at a festival wearing a wristband. The regular function of the wristband is to interact in a light show. However the battery of the system can deplete. If this happens, users can visit certain checkpoints at the festival terrain as will be discussed in Section 6.1, go to the bar that functions as a wireless power transmitter or ask other users (friends or strangers) that have a wireless power tranceiver for their energy to share. The use case diagram in figure 1 displays the interaction of a user, its friends and other users with the system. The internet of things in our system is displayed by a check in mechanism that sends data to a server. The server can then determine some recommendations for the user and his friends and can notify both. This will be discussed more into detail in Section 6.1.

The sequence diagrams display the different use cases. Figure 2 displays regular use of the system in its original design. A show object can detect user IDs by means of RFID tags and then send the

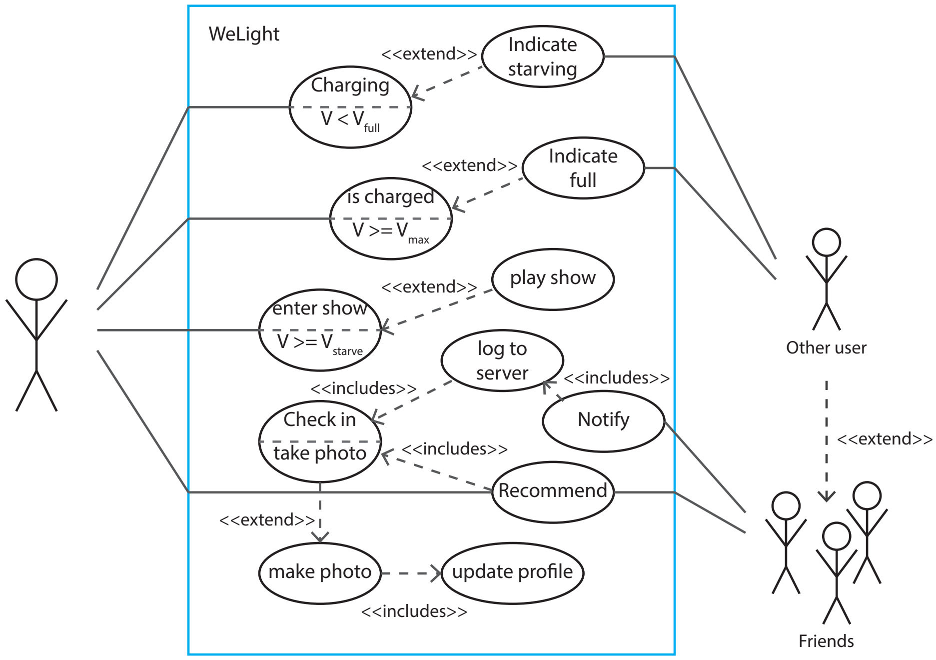

Figure 1: UML: Use case diagram of the system

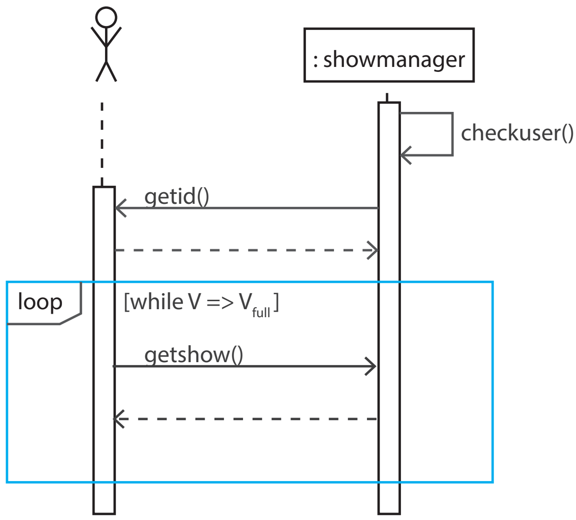

Figure 2: UML: Sequence diagram of the regular use of the product

instructions via RF signals to the wristbands. These will update their state and loop as long as the battery has a higher energy level than V_{full} as determined in Section 5.2.

Figure 3 follows this sequence and is initiated whenever the energy level of the battery falls below V_{full}. It will indicate towards the environment and other users that the battery is starving. The user can then ask another user for energy or visit an energy bar untill V_{full} is exceeded again. When V_{max} is reached the indication light will turn green as further charging will have no effect. These states are further discussed in Section 4.3.

Figure 4 shows the sequence diagram whenever a user connects to a checkpoint at the festival. Information about the time of the log, the position of the checkpoint and thus the concurrent nearest festival podium and the user ID is collected and send to the server. The database compares the information

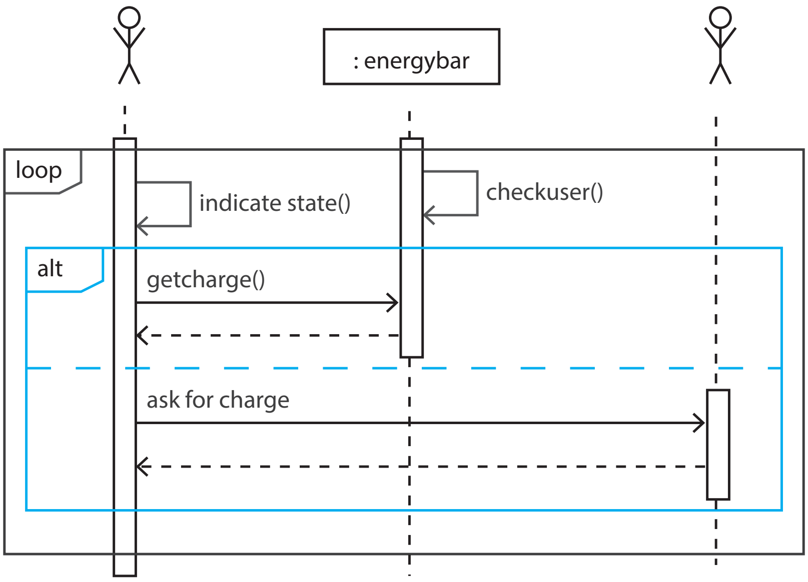

Figure 3: UML: Sequence diagram of the charging the system

with the users personal profile online and the current festival schedule and returns a recommendation. The user can select to inform his/her friends available on the personal profile. They might even add a personal message in order to agree on a meetingpoint.

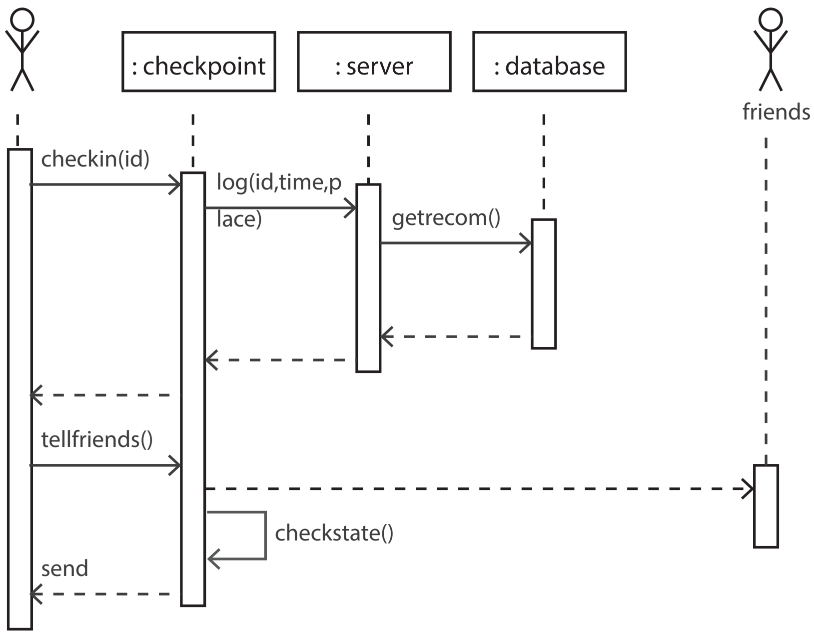

Figure 4: Sequence diagram of the internet of things

4.2 The wireless transfer system

Our major goal is to provide an efficient solution that best meets the challenges in battery charging systems using wireless power transfer. Those challenges include:

1. *Charging the battery as fast as possible.* Batteries can store a large amount of charge, but the charging speed limit get smaller with smaller sized batteries. Exceeding the charging current limit will deteriorate the battery's life and is more likely to happen when using smaller batteries as they have a lower charging current limit. To overcome this difficulty we propose adding a supercapacitor parallelly with a battery. The supercapacitor will function as a small buffer for charging the battery as it can hold a smaller amount of charge compared to the same size battery. Using a powerfull combination of a battery in parallel with a supercapacitor will offer a much faster charging cycle as supercapacitors are know to charge fast and will provide a robuster system for they have a longer cycle life [10], [7] as discussed in Section 3.
2. *Ensuring a long battery life by creating a large charge to discharge ratio.* In our scenario we don't want the user to be waiting for a longer time than 15 minutes for the wristband to charge. This introduces the need to store as much charging current in short intervals as possible. Batteries have a relatively low cycle life, making them unfit to be frequently charged and discharged. By positioning a supercapacitor in parallel with the battery, it acts as a buffer to store a large amount of charging current. Sequentially the same supercapacitor can use this current to charge the battery with a slow pace. This ensures a longer battery life in terms of a large charge to discharge ratio.
3. *Developing an efficient protocol for sharing the available charge.* We don't want to develop a wastefull system in terms of energy. For this reason we want to propose an efficient protocol that enures the available energy is efficiently used. By using UML state and sequence diagram we will display the efficient flows of energy. Based on these diagram we will develop the protocols on an arduino to demonstrate our working fully functional system as will be discussed in Section 4.4.

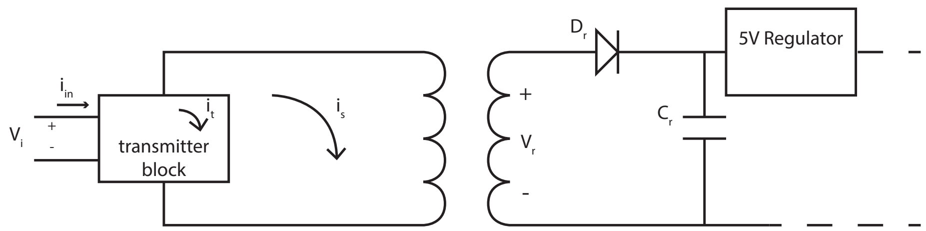

Figure 5: Design of the system

Figure 5 represents the general framework of a wireless power transfer system as proposed in the assigned paper [1]. In order to propose a system design applicable to the subject of wireless power transfer we will use this framework and come up with our own parameters and design for the application. To charge the application with a wireless power transmitting system a regulated voltage of 5V with a maximum current of 300mA is required. Based on these specifications we found a wireless power transfer set online [3] and purchased this set as seen in figure 6 to build our system with. The specifications of this set are mentioned on [3], but will be discussed more detailed in Section 7.

4.3 State analysis

The major goal of this report is to develop a real-world application. In order to do this, all real-world implications need to be taken into consideration. There are certain states in which the system can reside depending on its own battery state, the battery state of neighbour nodes and the availability of a energy bar or energy checkpoint. These states and their transmissions are displayed in figure 7. The battery can either be sufficiently full when exceeding a limit V_{full}, in a starving state when is drops below V_{full} or in a depleted state when it drops below V_{starve}. These parameters are further specified in Section 5.2. With help of the state diagram we can write protocols to accomodate the state changes. The figure displays a composed state called capable. This state encapsulates the behavior of the product whenever it is capable of doing something functional such as charging and running a show.

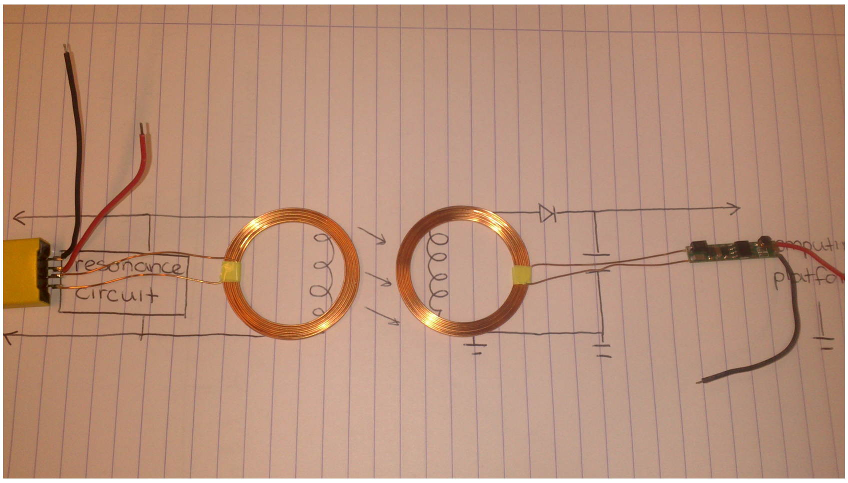

Figure 6: Engineeringshock Electronics Wireless power transfer set

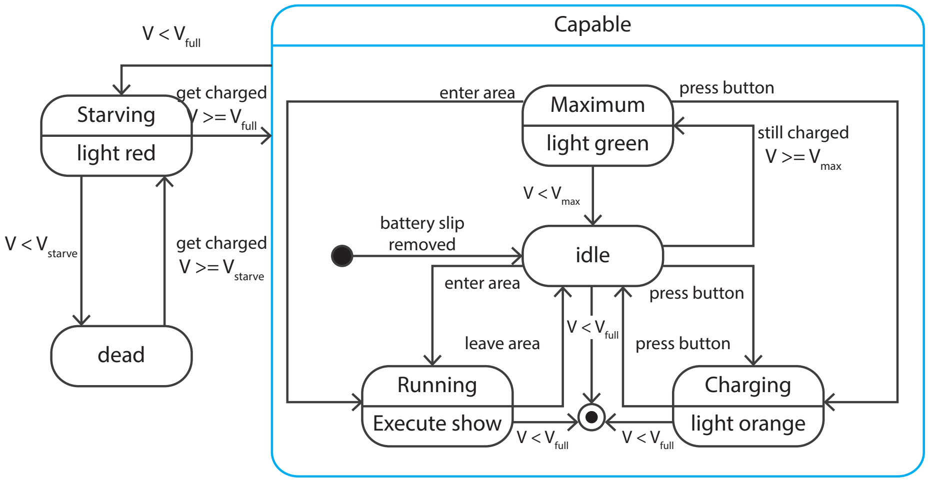

Figure 7: State diagram of a transceiving wireless power transfer system wristband

Whilst creating this state diagram we created several insights that introduced new features into the system:

- The need for a charging activator to accomodate the user with the option to choose to charge. To facilitate this we initially choose a button as an actuator. This could eventually also be integrated as an accelerometer or a more integrated button.
- An indication of V_{max}. The user needs to know when charging does not have any effect anymore. We will use a red light to indicate V_{max} is being reached.
- An indication for charging. To give the user a complete insight in the working principles of the system a blinking orange indicator is added whenever a wristband is receiving charge to indicate the wireless transfer is working properly.

4.4 Protocols

Charging protocols have to be designed to account for the state translations described in Section 4.3. We considered three possible energy charging scenarios: an infinite network like design where all nodes should stay alive, a hop-to-hop spread of energy that uses inter-module detecting or charge requests or an interactive behavior to selectively share energy. To stimulate interaction through this application we choose to apply a scenario where a user can choose to act upon energy requests and share with friends, or strangers. This is the best suiting approach considering the environment of a festival where you can meet new people and can "share the love".

Based on figure 7 we can determine all the possible state translation and the concurring protocols that are required. In this section we will generate code for the application that can be translated for an environment that fits the IC. For the IC we decided to choose the *Arduino Pro Mini* [2], a flexible small microcontroller for the arduino environment. For the real-world application we can fit the arduino in a relative small wristband. As the recognitions of the RFID tag that is included in the internet of things part is a passive component of the wristband, it is not included into the code. The actual code written for the Arduino Pro Mini can be found in the Appendix of the report.

We choose to work with the arduino mini pro as it is a great microcontroller to prototype with. It allows for several digital, analog and PWM pins and can be programmed using an external programmer. Once the program is finished in the Arduino environment, it can be uploaded using an external serial connector. This allows for easy debugging and iterative prototyping that can be connected with our circuit as it operates on 3.3V.

5 Analysis of the system design

In this Section we will discusse the specifics of the system we propose as well as introduce our validated model of the system. With this model we were able to display the charging profile in Section 5.2 and optimized for a charge to discharge ratio in section 5.3.

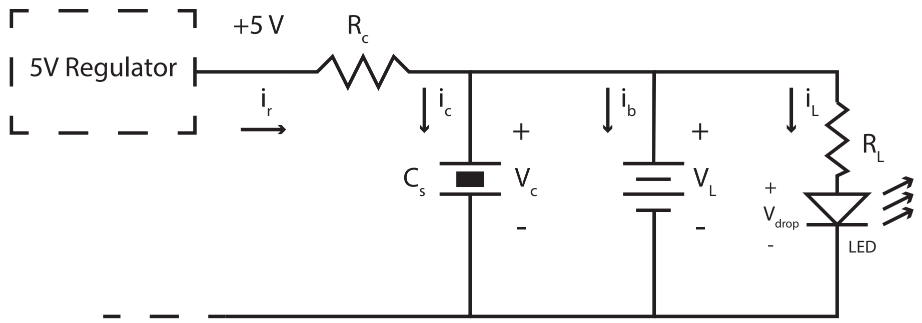

Figure 8: Design of the Receiver of the wireless power transmitting system

Figure 8 shows a low level schematic of the receiver and charging circuit which will be the main focus of our project. The induction current i_r induced by the transmitter through magnetic coupling will be the main source of charging current. The current i_c charges the super capacitor C_s up to the capacity of V_c, in our case $V_c \leq 5$ Volts as this is the maximum voltage rating of our supercapacitor, i_b charges the battery and i_L is consumed by the current limiting resistor R_L and a light source *LED*. Where $i_r = i_c + i_b + i_L$. Now in analysis lets first consider the efficiency η of the circuit. If P_o is the power consumed by the receiver and P_i is the power provided by the transmitter, ignoring small power drops across D_r and C_r then:

$$\eta = \frac{P_o}{P_i} \tag{1}$$

where $P_o = V_{reg} \times i_r$ and $P_i = V_i \times i_s$. The receiving battery can provide $V_l = 3$ Volts when fully charged. For a 3 Volts lithium-ion battery the output voltage normally drops by 0.2 Volts whenthe battery is at 40% of its capacity and can go to 2.6 Volts when it is almost drained [7]. Therefor a slight dim in LED brightness can be observed as battery drains with time. To ensure a normal brightness of our *LED* with a forward voltage drop of $V_{drop} = 1.7$ Volts we choose need a current of $i_L = 20$ mA. To determine the required resistance we used equation 2 and found $R_L = 65\Omega$

$$R_L = \frac{V_l - V_{drop}}{i_L} \tag{2}$$

Using $P_L = {i_L}^2 \times R_L$ we can determine the power rating of R_L that gives us $P_L = 400\mu$ Watts. This is the power dissipated at R_L and can be avoided if we use a LED that has exactly the same forward voltage drop V_{drop} as the battery output V_l. This will remove the need for the resistor R_L. A LED is very sensitive to even small changes in the applied voltage. A voltage change of 0.1 Volt can cause the LED current i_L to shoot up beyond the limits hence a more careful consideration is required if one chooses to omit the current limiting resistor R_L.

5.1 Battery Life

The battery that we are using has a capacity of 50 mAh, which means if a current I_B of 50 mA is continuously drawn from the battery, it can last for one hour. To determine the total battery life for our circuit we need to consider the total power consumed P_c, for our case $P_c = i_L \times V_l$ from which we can calculate the total life of a fully charged battery.

$$TotalBatteryLife = \frac{BatteryCapacity}{PowerConsumed} = \frac{I_B \times V_l \times 1hour}{i_L \times V_l} = \frac{50mA \times 3V \times 1hour}{20mA \times 3V} = 2.5hours$$

5.2 Charging Profile

This section discussing the working principle of the charging and discharging of the receiving circuit. According to the manufacturer specification $i_r \leq 400$ mA , which enforces the limit for the system to function properly. As can be seen in figure 8, the super capacitor C_s has a very low series resistance of 0.07Ω compared to $R_L = 65\Omega$. Therefore we can claim that $i_c \approx i_r$ during charging. If the $i_r(t)$ is not constant, but dependent on time, the capacitor charging is governed by the equation 3

$$V_c = V_{reg}\left(1 - e^{\frac{-t}{R_c C}}\right) \tag{3}$$

where R_c is the series limiting resistance of the receiver circuit whose value depends on the maximum value of i_r. C is the total capacitance of the supercapacitor which in our case $C_s = 5$ Farads. R_c can be chosen using $R_c = \frac{V_{reg}}{i_r}$ for a maximum allowed $i_r = 400$ mA which gives us $R_c = 12.5\Omega$

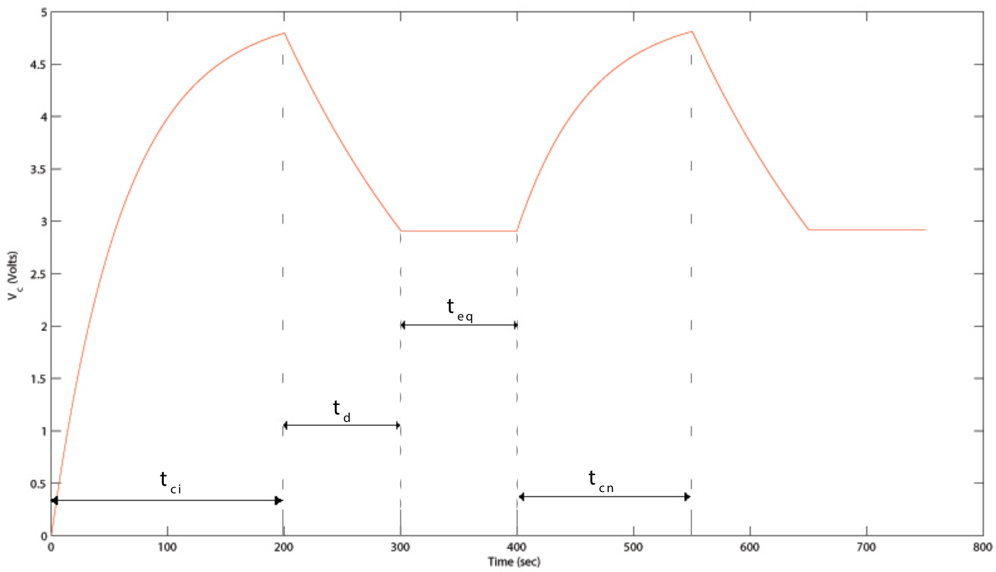

Figure 9: Charging profile of the super capacitor

Figure 9 displays the charging, discharging and idle profile of the supercapacitor during system operation. In the initial charging cycle t_{ci}, C_s is charged using $i_r(t)$ following equation 3. During the discharge cycle t_d, the $i_r(t) = 0$ and the discharge current is supplied in the form of i_b and i_L. Finally during the equilibrium cycle t_{eq} the voltage is reduced to equal the battery voltage ($V_l = 3$ V) such that no current flows between the battery and the supercapacitor and $i_b = 0$. At this stage only the battery's charge is used to power the LED. At last during the second charge cycle t_{c2}, the capacitor starts charging from an equilibrium voltage instead of 0 and is charged to V_{reg} untill the discharge cycle starts again. From the above figure we were able to determine appropriate values for the voltage limits as discussed in Section 4.3.We choose V_{max} = 3,2V, V_{full} = 3,0V and the starving limit $V_{starving}$ = 2,4V. These values can also be found in the code in the appendix.

5.3 Charge to discharge ratio

In this section we will discuss the time period t a system will keep running with a provided current i_r defined by the charge to discharge ratio C_r given as

$$C_r(t) = \frac{i_r(t)}{i_L} \tag{4}$$

where $i_r(t)$ is the current provided for charging at time t and is defined as

$$i_r(t) = \frac{5 - V_c(t)}{R_c} \tag{5}$$

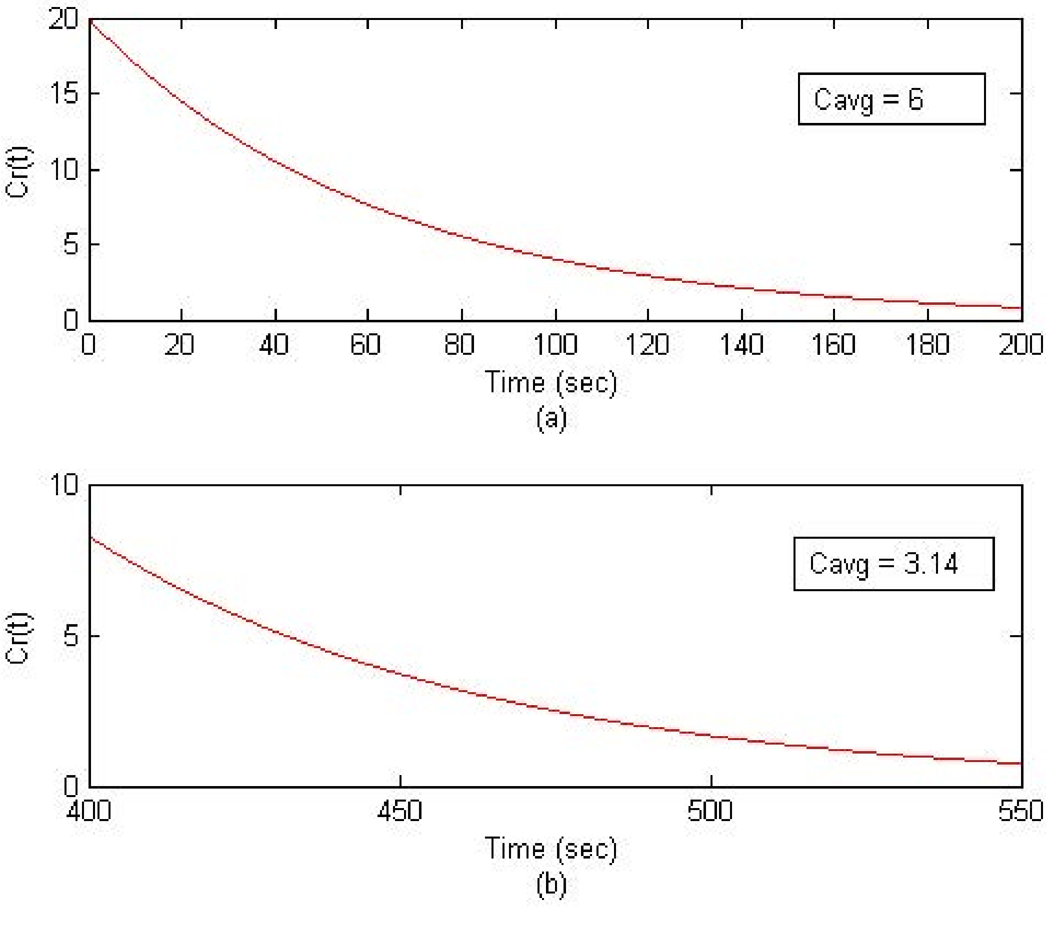

Figure 10: (a) Charge to discharge ratio for t_i cycle. (b) Charge to discharge ratio for t_n cycle

$C_r(t)$ is only meaningful during the time when $i_r(t) \neq 0$ which corresponds to time intervals t_i and t_n in the figure 9. Hence we can plot $C_r(t)$ for these intervals as shown in figure 10 (a) and 10 (b). From these figures we can observe that $C_r(t)$ decreases with time till the value of 2. This is because of the capacitor's charging nature, as C_s starts to charge up,$V_c(t)$ starts increasing which decreases the value of $i_r(t)$ and eventually $C_r(t)$.

To create a more meaningful analysis of the charge to discharge ratio one can find the average value of $C_r(t)$ using

$$C_{avg} = \frac{1}{T} \int_t C_r(t) \mathrm{d}t. \tag{6}$$

In figures 10 (a) and (b) for t_i and t_n we can see the value of C_{avg} to be 6 and 3.14 respectively. The value 3.14 for t_n is of more importance as this value represents the rest of the charging cycles through out the system operation. $i_r(t)$ is responsible for the decrease in $C_r(t)$ which means that the receiving energy is not fully exploited. C_{avg} can be further improved if we can somehow exploit the $i_r(t)$ to its maximum value for all times t. This can be achieved by using a component that can provide constant current regardless of the change at its output voltage. Such components have an internal DC to DC convertor and are referred as constant current capacitor/battery chargers. If such a component is added to charge the super capacitor than it is possible to get $i_r(t)$ as constant maximum allowed value for all times t.

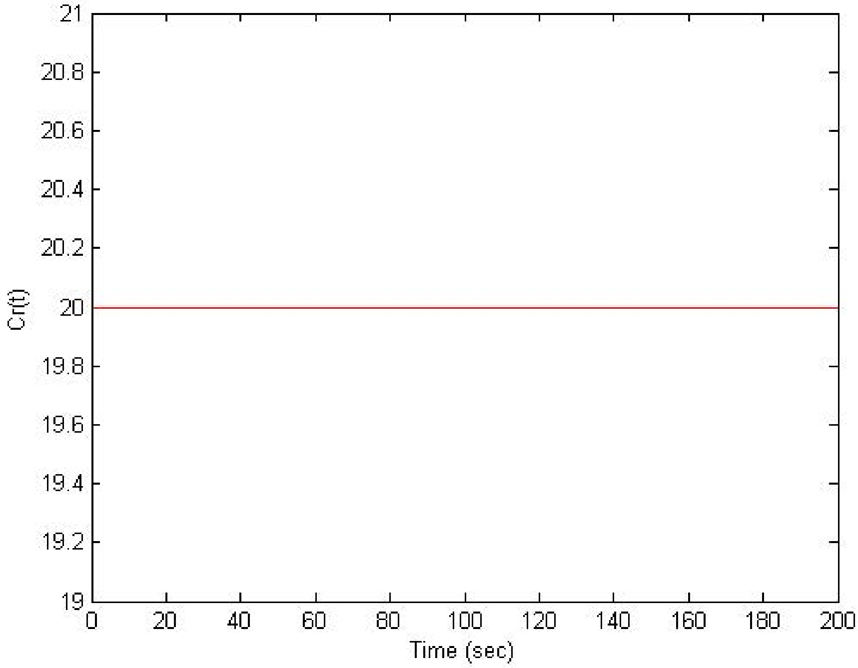

Figure 11: Charge to discharge ratio with constant charging current i_r

For a constant i_r, the $C_r(t)$ profile is shown in figure 11, using this model we can observe that $C_r(t)$ value has been improved to 20 and stays constant for all values of t.

6 The proposed system design

Figure 5 shows the proposed design of the system. The system includes a transmitter and a receiver with transmission and receiving coil respectively and a wireless power transmission based on the principle of magnetic induction [7]. The transmitter is powered by a voltage source V_i of 12 Volts, capable of delivering 400 milli-Amps of i_{in} current. i_c is the constant current that is consumed by the transmitting circuitry and i_s is the induction current which flows through the transmitter coil such that $i_{in} = i_c + i_s$. i_c is constant and depends on the transmitter inner circuitry power consumption, in our case $i_c = 100milli - Amps$. i_s depends on the distance between the two magnetically coupled coils. A bigger distance will decrease the i_s. Another factor that could improve i_s is adding an iron core between the two coils. Adding a core makes the magnetic coupling stronger and increases the i_s which enhances an overall efficiency of the system. The receiver circuit receives an induction voltage V_r, rectifies it through a rectifier containing a shotkey diode D_r and a capacitor C_r. A shotkey diode is used in order to have a good frequency response at the range of $300 - 400Khz$, the operating frequency of the frequency. The shotkey also ensures a lower forward voltage drop. The rectified voltage is then fed to the voltage regulator that produces a constant voltage $V_{reg} = 5Volts$.

6.1 The internet of things

The assignment of this report conveyed critizing and accessing system-level Internet of Things components in scientific literature. Because the assigned paper [1] did not include anything IoT related, we came up with our own idea. In this section we will provide a short introduction to the Internet of Things and its key features, we will also present our idea and focus on the practicality and entrpreneurial aspect of our idea.

The anatomy of Internet of Things is initiated by a certain event, that is detected and logged by devices that include self-properties [8]. This data is then uploaded by a ubiquitous and interoperable network. An analysis of this data can sequentially trigger certain events as a response. The intelligence of these systems lie in the adapting mechanisms that analyse and understand the environment in order to deal with the complex dynamics of a real-world environment.

Internet of Things has already been employed at multiple festivals and initially used as a ticketing solution in 2004 at the SXSW festival in Austin. IoT first introduced itself in the form of wristbands and cut down significantly on gate crashing and lost tickets [11]. SXSW announced that each tag contained a unique ID code, correlated with personal information availabe by SXSW [6]. Since then it has further been introduced at Coachella and Bonnaroo festivals [5] [4]. RFID tags now even support cashlesh payments and integration with social networks, allowing people to upload pictures to facebook via the so-called "Live Click Stations"[11]. It safe to say that the Internet of Things hasn't reached its peak yet concerning these social events and are worth looking into.

The users in our scenario are wearing a wristband containing the specified wireless power receivers. We will add some small features to the wristband to play into current trends concerning Internet of Things and music festivals. By adding a RFID tag into each wristband, users are assigned unique IDs that can provide unique entrance IDs or support cashlesh payments. Figure 12 displays our choosen chain of interactions considering the Internet of Things as will be discussed afterwards.

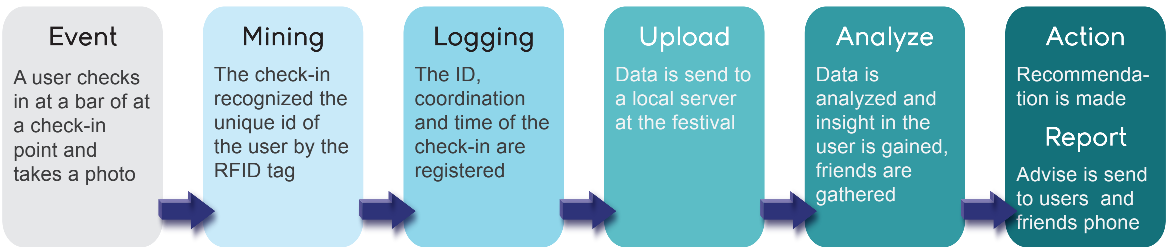

Figure 12: Internet of things chain of actions

In this report we want to focus on the fun factor of connecting with friends and strangers. Before arriving at the festival, users are assigned a unique ID when creating an account online. Optionally they can link their accounts with social media or friends and provide some preferences in music. When they arrive at the site and receive their wristbands, their unique IDs are connected with the wristband received. Whenever they charge their wristband at an energy bar or at check in points near every site of interest, their friends that are not near them will receive a message containing their location and if made, an image at the check-in location. Based on certain check-in's at time in the schedule of the festival, the system can recognize their interests (if not already mentioned in their id page online) and provide recommendations.

Our system goes beyond simply assigning a unique ID to a user, it also adds functionality and connects IDs to exchange information. This doesn't just improve the experience of the user, but it gives the organization a better insight into the behavior of their visitors.

7 Results

Figure 13 shows charge to discharge ratio from the practical system. Compared to the theoretical result shown in figure 10 (a) a clear degradation can be noticed. The average value has been reduced from 6 to 4.75. This is due to two major reasons, the imperfection of practical components and the assumptions taken in theoretical model. In theoretical model we made the assumption that during the charge cycle there is no current flowing into the battery and $i_r \approx i_c$, where as in reality a small current is flowing into the battery hence producing the non ideality in the actual results.

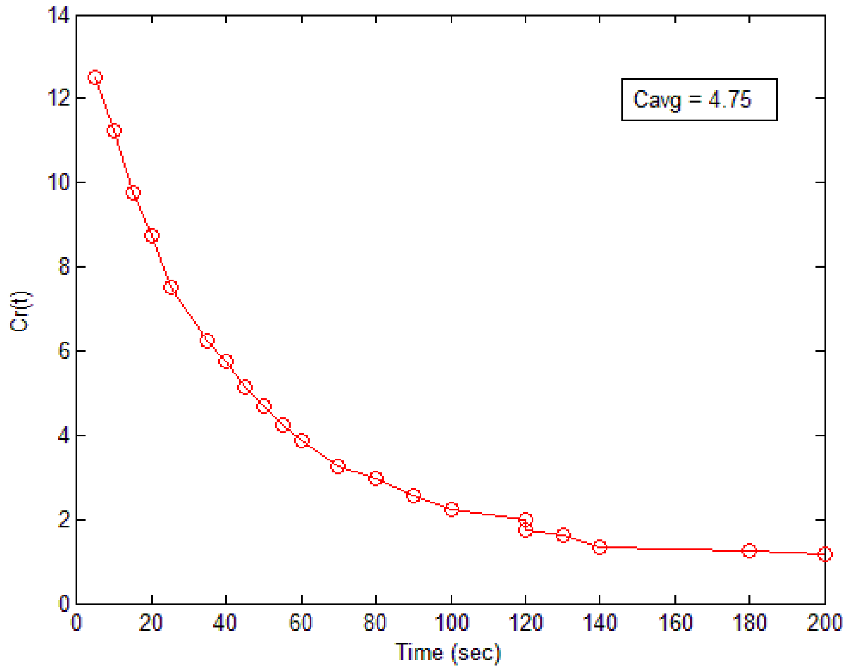

Figure 13: Charge to discharge Ratio

Distance between two coils (cm)	Efficiency (%)
0	70
1	60
2	50
3	40
4	30

Table 2. Distance vs Efficiency

8 Conclusion

conclusion

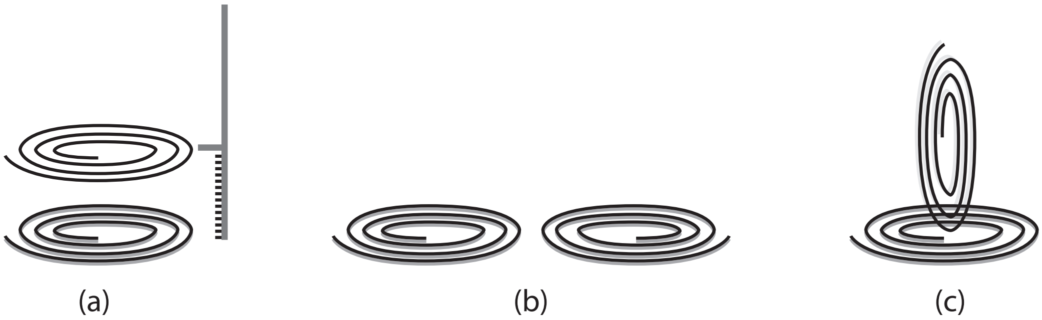

Figure 14: Orientations of the test set-up

9 Future works

Say something about future work

might need to find out if the radio frequency communication does not interfer with the charging and vice versa

maybe they can introduce some kind of pattern recognition in where people are at the festival by checking the RFID tags.

The major technical challenge is to achieve large value for charge to discharge ratio, which means that during the charging cycle one has to provide large amount of wireless power. This can be achieved by using high power IC's that can with stand high currents without any failure. Other challenges involve making the system compact enough so that it can fit in one wrist-band and increasing the distance between the wireless transceiver and receiver. Increasing the distance without losing significant efficiency would require a completely new technique in wireless power transmission which is still a hot topic of research. However, making the system compact can be achieved by taking extra care in selecting the components which may require exploring many different vendors.

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A Arduino Pro Mini code

```
/*******************************************************************************
 *  This is a program to facilitatite a wireless power transfer protocol
 *  for the IOT project on TU Delft by M. Wasif & I.C.T.M. Speek
 ******************************************************************************/

// Variable to save battery and pin declaration
int voltage = 0;      // variable to read voltage level battery into
int Battery = A0;     // Analog pin to read battery voltage

// Variables for debouncing the button
int chargeBtn = 10;          // Digital pin for the charge Button
int reading = 0;             // Variable to store reading Button
int buttonState;             // Current reading of the Button
int lastButtonState = LOW;   // Previous reading of the Button

// Time measured in miliseconds to debounce the buttons
long lastDebounceTime = 0;   // Last time the the Button was pressed
long debounceDelay = 50;     // The Debounce time

// Variables for detecting the show
int showDetect = 11;         // Digital pin upon which the show is detected
int show;                // Boolean to save the show state in

// RGB pins
int LEDr = 7;        // Digital pin for r from RGB LED
int LEDg = 8;        // Digital pin for g from RGB LED
int LEDb = 9;        // Digital pin for b from RGB LED

// Declare the states as an enum
enum StateVariable{
  maximum,
  idle,
  charging,
  running,
  starving,
  dead
}
state;

// Map all the V variables to the analog 2^10
#define Vmap / 3.2 * 1023
// Declaration of Vmax, Vfull, Vstarving and Vdead
// Varies between 0 and 5 V, but should map between 0 and 1023 for Analog
// Value might be slightly off as int rounds off
const int Vmax = 3.2 Vmap;
const int Vfull = 3.0 Vmap;
const int Vstarving = 2.4 Vmap;
const int Vdead = 2.2 Vmap;

// Initialize the system
void setup(){
  // set serial monitor at 115200 boudrate
  Serial.begin(115200);
  // Declare the battery energy level pin as (analog) input
  pinMode(Battery, INPUT);
  // Declare the charge button as input
  pinMode(chargeBtn, INPUT);
  // Declare the show as an input value
  pinMode(showDetect, INPUT);
  // declare RGB pins as output
  pinMode(LEDr, OUTPUT);
  pinMode(LEDg, OUTPUT);
  pinMode(LEDb, OUTPUT);
  // Initialize the state as idle and show as false
  // as you receive a wristband at the entrance of the festival
  state = idle;
  show = LOW;
}
```

```
// Functional part of the system
void loop(){
  // Reads the energy level and buttonstate of the battery and saves it
  // at the start of the program loop
  voltage = analogRead(Battery);
  reading = digitalRead(chargeBtn);
  show = digitalRead(showDetect);

  // If the switch changed, due to noise or pressing:
  if (reading != lastButtonState) {
    // reset the debouncing timer
    lastDebounceTime = millis();
  }
  if ((millis() - lastDebounceTime) > debounceDelay) {
    // whatever the reading is at, it's been there for longer
    // than the debounce delay, so take it as the actual current state:
    buttonState = reading;
  }

  // A switch case based on the state of the system
  switch (state) {
  case idle:
    // Perform idle tasks
    Serial.println("Idle");
    digitalWrite(LEDg, LOW);
    digitalWrite(LEDr, LOW);
    digitalWrite(LEDb, LOW);
    // Check if state translation is necessary
    if (voltage >= Vmax){
      state = maximum;
      break;
    }
    else if (buttonState == HIGH){
      state = charging;
      break;
    }
    else if (show == HIGH){
      state = running;
      break;
    }
    else if (voltage < Vfull){
      state = starving;
      break;
    }
    break;
  case maximum:
    // Perform maximum tasks
    Serial.println("Maximum");
    digitalWrite(LEDg, HIGH);
    digitalWrite(LEDr, LOW);
    digitalWrite(LEDb, LOW);
    // Check if state translation is necessary
    if (voltage < Vmax){
      state = idle;
    }
    // if user wants to charge, break state and charge
    else if (buttonState == HIGH){
      state = charging;
      break;
    }
    else if (show == HIGH){
      state = running;
      break;
    }
    break;
  case charging:
    // Perform charging tasks
    Serial.println("Charging");
    digitalWrite(LEDg, LOW);
```

```
  digitalWrite(LEDr, LOW);
  digitalWrite(LEDb, HIGH);
  delay(500);
  digitalWrite(LEDg, LOW);
  digitalWrite(LEDr, LOW);
  digitalWrite(LEDb, LOW);
  delay(500);
  // Check if state translation is necessary
  if (buttonState == LOW){
    state = idle;
    break;
  }
  else if (voltage < Vfull){
    state = starving;
    break;
  }
  break;
case running:
  // Perform running tasks
  Serial.println("Running");
  digitalWrite(LEDg, LOW);
  digitalWrite(LEDr, LOW);
  digitalWrite(LEDb, LOW);
  // Check if state translation is necessary
  if (show == LOW){
    state = idle;
    break;
  }
  else if (voltage < Vfull){
    state = starving;
    break;
  }
  break;
case starving:
  // Perform starving tasks
  Serial.println("Starving");
  digitalWrite(LEDg, LOW);
  digitalWrite(LEDr, HIGH);
  digitalWrite(LEDb, LOW);
  // Check if state translation is necessary
  if (voltage >= Vfull){
    state = idle;
    break;
  }
  else if (voltage < Vstarving){
    // not necessary in actual implementation
    // the IC will not receive any power anymore by now
    state = dead;
    break;
  }
  break;
case dead:
  // Play Dead - not necessary as IC is not powered
  Serial.println("Dead");
  digitalWrite(LEDg, LOW);
  digitalWrite(LEDr, LOW);
  digitalWrite(LEDb, LOW);
  // Check if state translation is necessary
  if (voltage >= Vstarving){
    state = starving;
    break;
  }
  break;
}

// save the reading. Next time through the loop,
// it'll be the lastButtonState:
lastButtonState = reading;

// Small delay to accomodate stability
```

```
  delay(1);
}
```