Automatic Light Switch Controller

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1. Introduction

1.1 Objective

Many homeowners experience coming back from work or trips to realize that they had forgotten to turn the lights off in one of the rooms if not multiple. Although it may not seem to be the most critical mistake, people would be surprised at how much energy and money they are wasting from such an overlooked mistake. In fact, lighting accounts for approximately ten percent of electricity in homes**[1]**. An average of 1,105kWh of energy has been consumed in 2015 in households in the U.S.**[1]**

With around 25% of households having 40 or more bulbs**[1]**, a considerable amount of waste of energy can be prevented by making sure lights are turned off when the owner leaves his or her home. To guarantee that the user would be turning all lights off when leaving the house without having to prioritize the action, we would use a device that can be attached to a necessity that the user would never leave the home without. When the device is at a reasonable distance from the home to conclude that he or she has left the home, the controller inside the home would shut all lights off. With a device that simply detects distance from home, the user would not be worrying about wasting energy or electricity bills.

1.2 Background

Our device would tackle the same problem of leaving the house without turning off the lights in the coat hanger light switch controller project with a completely distinct solution. Instead of using a pressure sensor device on a coat hanger to detect the absence of a coating/purse, our device would consist of an UWB transmitter and receiver pair that would be used to calculate the distance between the two modules. If the detected distance exceeds 100m, the microcontrollers will be signalled to turn off the light switches via Bluetooth.

Other products with similar intentions can be seen in the market, some of which use motion sensors to detect the presence of the person in the room and turn off the switches immediately if not. This is different from our intended design, since we wish to detect that the user is completely out of the home and turn the light switches off if they were forgotten. Other forms include controlling the switch via an app, which does not provide the autonomous nature of our device.

1.3 High-level requirements list (NEED CHECK)

1. At least 95% success rate in determining the absence/presence of user at home via distance measurement.
2. At least 95% success rate in turning lights on/off upon signal of presence/absence from master bluetooth microcontroller.
3. Battery life of at least one week for portable device.

2. Design

2.1 Block Diagram

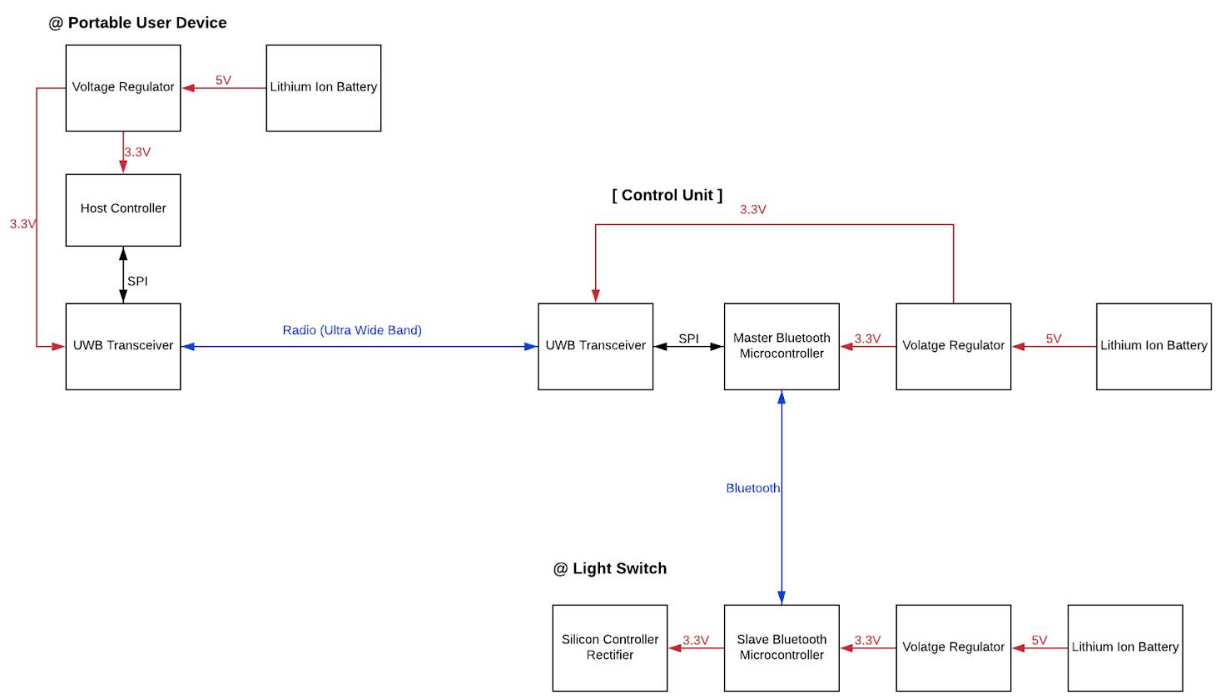

Figure 1: Block Diagram

The upper left-hand-side of the block diagram would be attached to the user's everyday belongings, which consists of a battery and voltage regulator as a power unit and a generic host controller and an always-on UWB transceiver(mainly receiver). The right-hand-side of the portable device would be the main controller module of the design. This would also consist of a power unit and an UWB transceiver(mainly transmitter). As the detected distance from the receiver exceeds 100m, it will communicate with the master Bluetooth microcontroller via SPI.

Then, the master Bluetooth microcontrollers will signal the slave controllers at each light source to signal its corresponding Silicon Controller Rectifier.(SCR). The bluetooth microcontrollers and the host controller for the UWB chip will be powered by standard lithium-ion batteries with a voltage regulator to provide a 5V power supply.

2.2 Physical Design

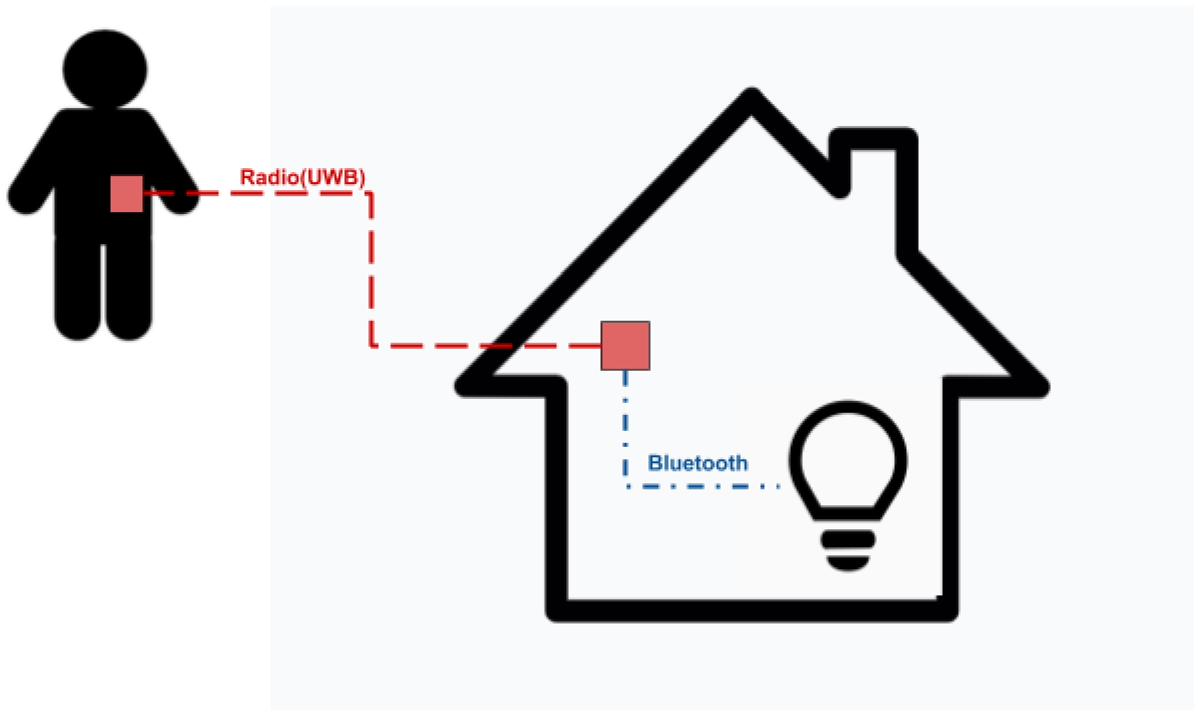

Figure 2: User, At-Home Controller. Light Unit

2.3 Functional (Block) Overview and Requirements

2.3.1 Control Unit

The control unit consists of the master bluetooth microcontroller and its UWB IC. This UWB IC together with the UWB in the receiver module performs distance measurement. More information on this process is available in the transmitter unit section below. When a distance between the two modules is greater than 100m, the bluetooth microcontroller will send packets to its slave microcontrollers which will turn off the lights. The control unit must also send an ON signal to the other microcontrollers when the distance drops below 5m.

Bluetooth microcontroller:

This module will be an nRF52832 module or similar. This is a bluetooth enabled SoC containing an ARM M0 core and on-chip memory. This module must also maintain a serial connection with the UWB IC to receive and compare distance measurement with the 100m and 5m cutoffs**[2]**. Due to limitations of BLE chips, usually a max of two devices may be paired to a master device. One possible solution may be to use a bluetooth mesh, or multiple master devices. This is an option we will explore more before the design document.

Requirement
- Must support SPI interface as external host (general-purpose processor) - Must be powered by a low voltage ~ 3.3V. - Must support minimum 0.27 Mbps throughput (low-end BLE)

Transmitter DW 1000 Chip:

The transmitter unit will be an UWB IC. The transmitter unit and receiver unit will together implement a protocol known as single-sided two-way ranging (SS-TWR). **[3]**

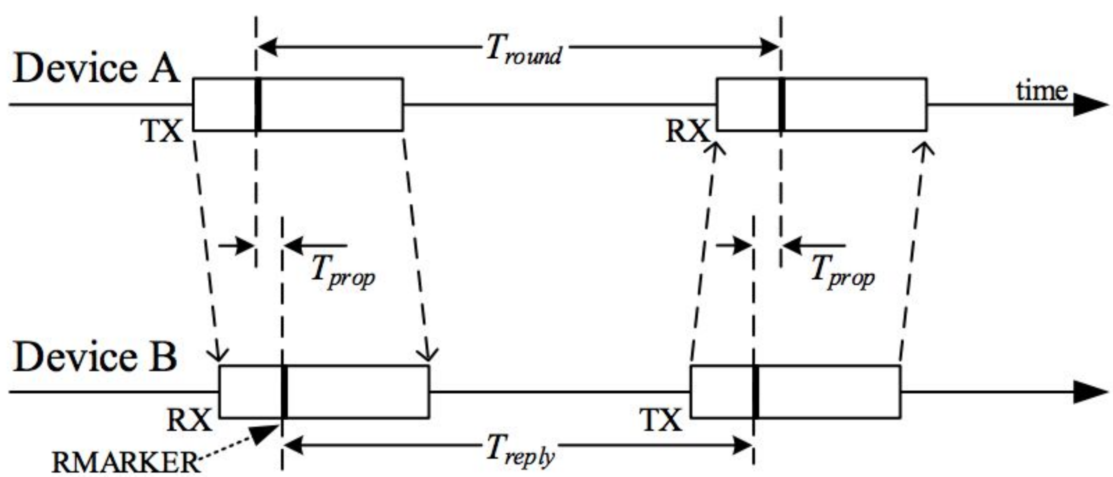

Figure 3: Single-sided Two-Way Ranging Protocol

When a packet is sent by the initiator (TX), it is timestamped. Similarly, the packet is also timestamped by the receiver upon arrival. When the packet is sent back and timestamped again by each device, the reply time and round-trip time can be computed independently. Because both

T_{reply} and T_{round} are computed with respect to each device's local clock, synchronization is unnecessary. The propagation time can then be estimated as below.

$$T_{prop} = \frac{1}{2}(T_{round} - T_{reply})$$

Eq. 1: Propagation time for SS-TWR

Error in distance estimation increases as T_{reply} grows large, so it is possible that we may implement double-sided two way ranging, an improvement on the above method that requires an additional round-trip of a second packet. Even with 20ppm clock drift, a distance resolution of up to 2.2mm with a range of 100m is attained (DW1000 User Manual).

When the protocol completes, the transmitter module will send a distance estimation to the master microcontroller via SPI.

Requirement
- Must transmit data packets to Bluetooth microcontroller at less than 8^28 Mbps (max value set for SPI slave by nRF52832) - Must support at least 6GHz RF band - Must be powered by a low voltage at or below 3.3V (lithium-ion battery).

Receiver DW 1000 Chip:

The receiver will be paired at all times to the transmitter and configured to output at max power, but respond with acknowledgment packages only when a package from the master transmitter is successfully received.

As aforementioned, the receiver module will consist of a UWB IC and power supply. Since the UWB IC needs to be connected to a master controller to function as a slave, we will use a generic microcontroller LPC8N04. The receiver does not need to send measurement data to an external processor, but does need to maintain an SPI interface with a logic/state machine that will trigger transmission of packages.

To save power consumption on the device that the user will carry around and support a battery life of at least one week, the mostly receiving transceiver module will be operating at the low-power listening mode, where the DW1000 is at a SLEEP state and wakes up periodically and samples to check for transmitted preambles. **[7]**

Requirement
- Must support at least 6GHz RF band - Must be powered by a low voltage at or below 3.3V (lithium-ion battery).

Host Controller:

Requirement
- Must support slave SPI communication - Must be powered by a low voltage at or below 3.3V (lithium-ion battery).voltage

2.3.4 Light Switch Subsystem

This subsystem is essentially a silicon controlled switch circuit. We will replace the switching circuit in each light switch to be modified with a SCS. The SCS is a circuit composed of two BJTs (bipolar junction transistor) with four inputs (anode, cathode, cathode gate, and anode gate) and three modes of operation:

1. *Forward blocking mode*: Anode of device is given positive voltage, cathode is given negative voltage, and gate is left floating (0 potential). No forward current flows with a minimal leakage current flowing. This is an inactive mode for our purposes.

2. *Forward conduction mode:* Reached if breakover voltage is exceeded or a positive pulse (digital signal) is applied to the cathode gate. For our system we should choose a breakover voltage much larger than the voltage required for the light switch such that this mode is only reached when the bluetooth microcontroller activates directly.

3. *Reverse blocking mode:* Unused.

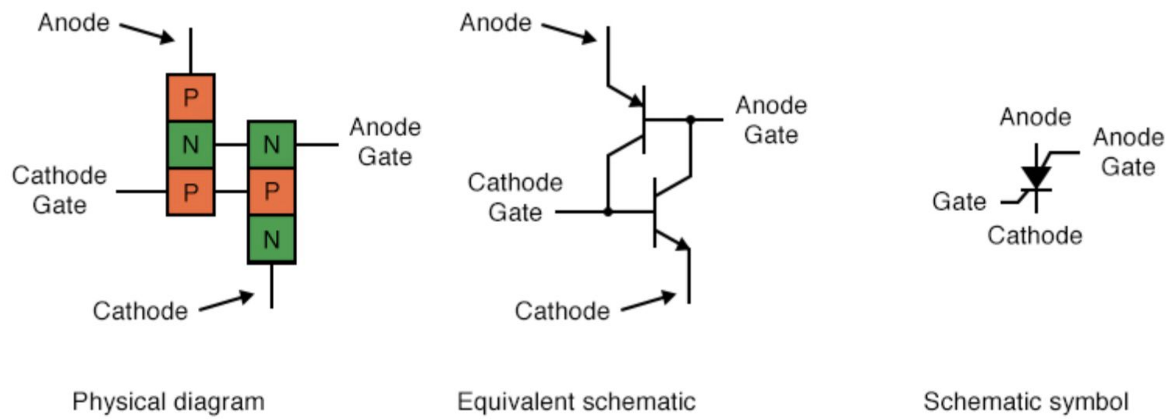

Figure 4: Silicon Controlled Switch

The wall-voltage will be connected to this system at the anode gate, with the cathode being connected to the load (light-bulb). The SCS can be forced into forward conduction mode by applying a positive pulse to the cathode gate. To turn the current to the lightbulb off, we can apply a low signal to the anode, since a positive voltage between the anode and cathode must be maintained to stay in forward conduction mode **[9]**. Since it is likely that the voltage at the cathode will be large, we will require an op-amp to amplify the output voltage from the microcontroller to the anode of the SCS.

Requirement
- Must amplify output signal of microcontroller to the switching circuit - Must allow transition between forward blocking and forward conduction modes (turning light bulb on and off) by applying a single high or low pulse from the microcontroller

2.3.5 *Power Subsystem*

Lithium-ion batteries, voltage regulators, and an accompanying power bus to drive the circuitry in both the control unit, transmitter/receiver units.

Requirement:

- Must be able to provide 1.7~3.6V range of power supply to the control unit, transmitter and receiver units.

2.4 Risk Analysis

The greatest risk in this project which could prevent success lies with the bluetooth devices. As aforementioned, using a bluetooth mesh may be necessary which would make this subsystem significantly more difficult to implement.

The UWB IC may also face attenuation problems caused by thick walls in the house, particularly if we are operating at 6 GHz frequency. This would cause problems for the user in their own home as lights may turn on and off erratically.

3. Ethics and Safety

The most important relevant IEEE Code of Ethics**[6]** in the context of our project is the first, which states that our device must prioritize the safety of the consumer and the environment. In the development of the product, we will also make sure to follow the seventh IEEE Code of Ethics**[6]** and openly accept honest criticism of other group members and course staff to help better the design of the product and not take credit of those whose work was involved in the progress. We will also respect all involved so that everyone is respected and not discriminated based on factors implied in the 8th IEEE Code of Ethics**[6]**. The project will involve no injuries caused due to malicious behavior according to the 9th Code**[6]** and keep a professionally supportive environment for all colleagues involved by the last Code of Ethics**[6]**.

4. References

[1] *Regional variations in household lighting consumption driven by bulb choice and bulb count.* U.S. Energy Information Administration. (Feb. 25, 2019). Retrieved from: https://www.eia.gov/todayinenergy/detail.php?id=38452

[2] *nRF52832 Bluetooth v4.2 module.* nRF52832 Datasheet. Nordic Semiconductor ASA. (2017-10-10). Retrieved from: https://infocenter.nordicsemi.com/pdf/nRF52832_PS_v1.4.pdf

[3] *DW 1000 Radio IC.* DW1000 Datasheet. Decawave Ltd 2015. Version 2.09. Retrieved from: https://www.decawave.com/sites/default/files/resources/dw1000-datasheet-v2.09.pdf

[4] *32-bit ARM Cortex -M0+ microcontroller.* LPC8N04 Datasheet. NXP Semiconductors. Rev. 1.4 - (2018-6-8). Retrieved from: https://www.nxp.com/docs/en/data-sheet/LPC8N04.pdf

[5] *Lithium-Ion Battery.* NCR18650BF Datasheet. Panasonic. Retrieved from: https://b2b-api.panasonic.eu/file_stream/pids/fileversion/3446

[6] 7.8 IEEE Code of Ethics. (2004). *IEEE Policies, Section 7 - Professional Activities (Part A - IEEE Policies).* Retrieved from: https://www.ieee.org/about/corporate/governance/p7-8.html

[7] *DW 1000 Radio IC.* DW1000 User Manual. Decawave Ltd 2015. Version 2.09. Retrieved from:https://www.decawave.com/sites/default/files/resources/dw1000_user_manual_2.11.pdf?fbclid=IwAR3kuqh6ElrlnjfWNQE1BP7qutd5mbNjfpVBKMCRqsPVk-5f-4H_9w4Wk6w

[8] *LP 2950*. LP2950, LP2951, NCV2951 Datasheet. On Semiconductor. (October 2019) - Rev. 31. Retrieved from: https://www.onsemi.com/pub/Collateral/LP2950-D.PDF

[9] *The Silicon-Controlled Switch (SCS)*. Lessons in Electrical Circuits. All About Circuits. Retrieved from:
https://www.allaboutcircuits.com/textbook/semiconductors/chpt-7/silicon-controlled-switch-scs/