Alex Dicheva (dicheva2)
Wyatt Sass (wpsass2)
Patrick Wang (pw16)

A Cheaper Alternative to Temperature Controlled Sleep

Project Proposal

Introduction

Problem:

Much research has been done on the impact temperature has on your sleep. In general, the body prefers to feel warmth in the time before trying to fall asleep to not only ensure relaxation but also allow for a faster decline in body temperature. As you settle into sleep, starting around 10 min before falling asleep, it is helpful to have a steady decline in room temperature to match your body's decline. Body temperature lowers throughout your sleep cycle due to a decrease in the body's ability to thermoregulate, which makes sleep easier in lower temperatures and has driven recommendations for low bedroom temperatures at night, such as 66-70 degrees [1]. Various efforts have been made toward temperature regulation while we sleep to improve the quality and length of sleep. One solution is a Smart Thermostat; however, this requires heating the entire room or the entire home. There are also temperature-controlled bed sheets or duvets, such as the BedJet ($1329), Smartduvet ($1555), and EightSleep ($2195) [2, 3, 4]. All of these are priced at over $1000, making them unaffordable for the average consumer. While each of these solutions takes a different approach to the problem, they are all too expensive for the average consumer to even consider trying out.

Solution:

Heated blankets are used to stay warm in colder weather, and they can be found just about anywhere, costing between $25-50. It can feel quite comfy to hug one before going to sleep to help relax, but the blanket's warmth can make staying asleep the whole night difficult. However, with some modifications to a heated blanket, Temperature Controlled Sleep can be cheap and attainable for everyone.

We will add temperature sensors to the outer layers of the heated blanket to track the temperature of the blanket within its environment. Another small sensor (like an IMU) can determine when the user's movements slow down, indicating that they may have fallen asleep. Using this data, we will create an app that allows the user to set a desired temperature for each part of their sleep routine. We will provide temperature recommendations, such as warmth before sleep, a gradient decline in temperature based on the user's desired time of sleep and their actual sleep time, and lower temperatures throughout the night. Finally, the user will have the option to gradually increase the temperature in their preferred morning hours to make waking up easier and serve as an aid to an alarm clock. Ideal sleeping temperatures vary from person to person, so users will be able to adjust each of these parameters. To receive feedback on the quality and length of their sleep, users will be able to track sleep time and movements in their sleep provided by the accelerometer data. This data will be stored over time to allow users to see whether their temperature adjustments are in their favor and edit accordingly. Ultimately, this serves as a much cheaper alternative for users to optimize their sleep by improving upon existing products that are already commonplace.

Visual Aid:

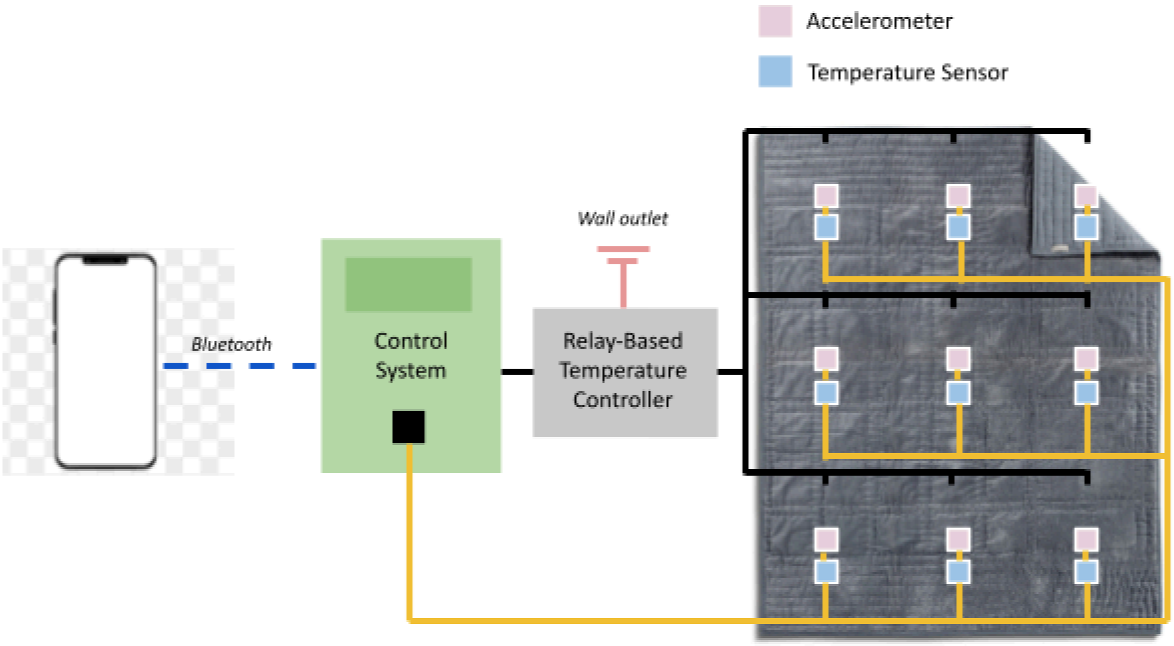


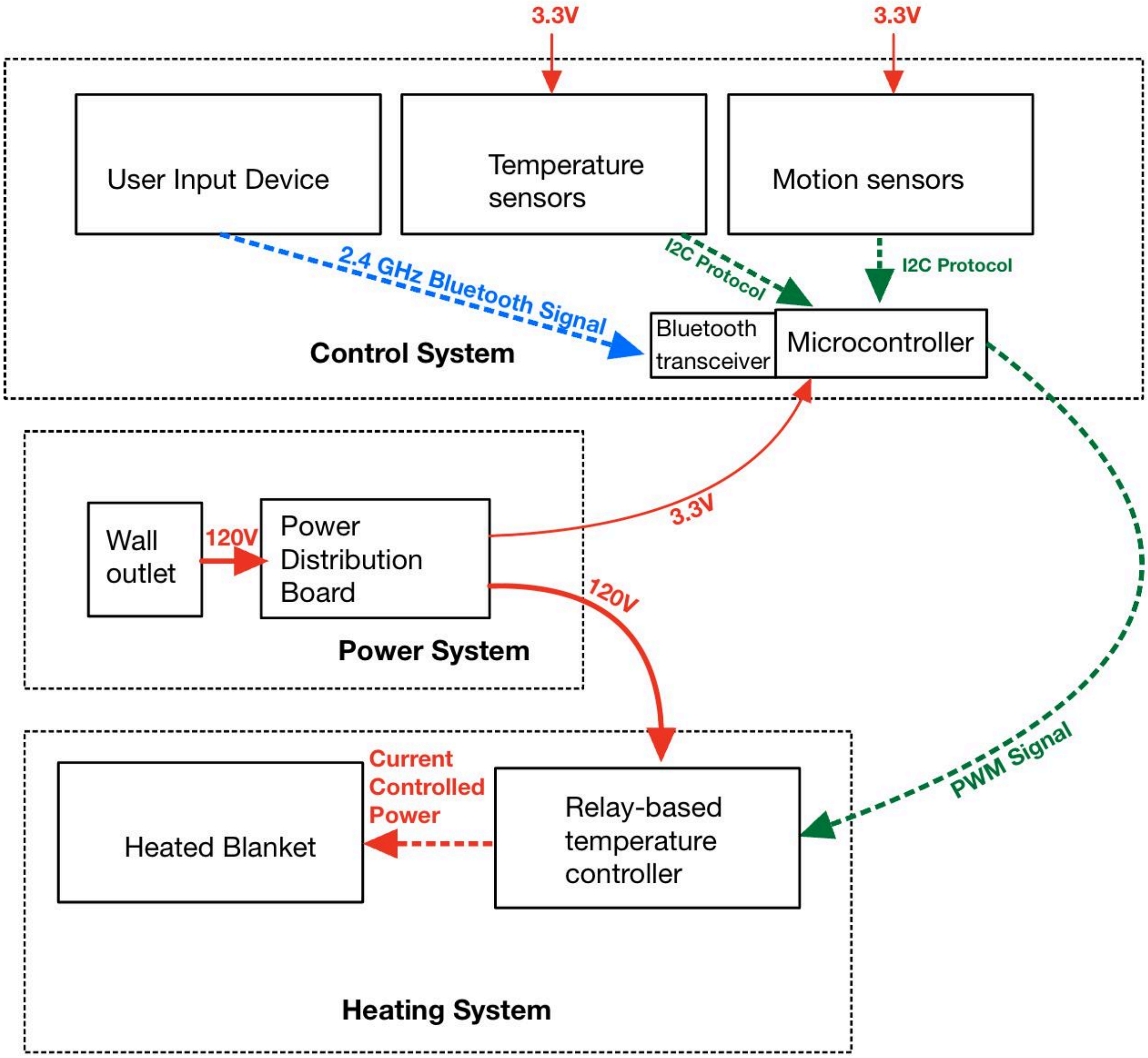
Fig. 1. Diagram components adapted from [5, 6]

High-level requirements:

- The user will be able to set the temperature remotely through an app, and the blanket will be able to control. Further, they will be able to schedule a temperature for 10 min after the initial temperature is reached. While the user lies under the blanket, the heating coils will reach that temperature (+/- 5 degrees Fahrenheit), and that temperature will be presented on the app. The blanket will be able to maintain that temperature for over 10 minutes, and adjust to the next target temperature under the same requirements.
- When a user gets under the blanket, the blanket can detect the user's movements spanning greater than 3 inches (+/- 1.5 inches) or with acceleration greater than 10 m/s^2 (+/- 1 m/s^2). This data will be relayed to our app, and the controller can use this data to detect a "sleeping" state after a period of non-movement.
- The temperature reading of the blanket should be broken down into 9 distinct zones. The blanket should be able to determine the absolute temperature within each zone (+/- 2.5 degrees Fahrenheit), and it should be accurate within a 3-inch radius. This temperature will be displayed on the app.

Design

- **Block Diagram:**



Subsystems:

- **Power Subsystem**
    - **Overview**: The power subsystem will be responsible for supplying the other two subsystems with the power they need to function. The subsystem will need to plug into a wall outlet. The subsystem will supply the heating subsystem with 120V AC and supply the control subsystem with constant 3.3V DC.
    - **Requirements**:
        - The subsystem will include a cord connecting a wall outlet (120 V) to a power distribution circuit. The power distribution will be used to run the other two subsystems in parallel.
        - The control subsystem will require 3.3V, which it will receive from an AC/DC buck converter that will take the 120V AC down to 3.3V DC, and a parallel capacitor will be added to keep the voltage stable.
        - The heating system will be in parallel and take on the full 120V of AC power. So, no voltage conversion will be needed for the heating system.
            - This subsystem will be important when implementing the heating system, especially if our goal is to keep our entire blanket at a steady temperature. We need to be able to provide a steady 120V AC to each of the coils for each of them to heat up properly. If the magnitude of the voltage varies across coils, this will lead to uneven heating.
    - In short, this subsystem needs to be able to supply 120V (+/- 5V) of AC power to the heating subsystem and 3.3V (+/- 0.3V) of DC power to the control system, and this power needs to remain constant over a period of fifteen minutes.
- **Control Subsystem**
    - **Overview**: The control subsystem will use input from three different sources and use the input to send PWM control signals to the heating subsystem. First, the microcontroller will receive Bluetooth signal inputs from the user input device, which will most likely be an iOS or web application, in the form of a temperature/heating setting and optional inputs like whether the user is ready for sleep, how long they would like to sleep, how they would like the temperature to change throughout the night, and perhaps other options. The microcontroller will also be receiving inputs from temperature and motion sensors through packet-based protocols and will need to determine whether to raise the temperature or drop the temperature according to all three input sources. The microcontroller will then send signals to the heating subsystem to adjust the heat setting.
    - **Requirements**:
        - This whole system will be powered by a 3.3 V parallel network.
        - It will include a PCB with a microcontroller of the STM32F series, with at least 18 GPIO pins, and at least 9 PWM outputs, and it will also have an HC-05 Bluetooth chip attached to the serial IO.

        - The blanket will be divided into 9 rectangular sections in a 3x3 pattern, each with a temperature sensor and an accelerometer in the center. These temperature sensors and accelerometers will be used to give feedback to the microcontroller.
            - Each accelerometer (LSM6DSM) will contribute to checking whether the user is asleep based on whether the accelerometers record movement and this will contribute to the calculation of the optimal temperature to improve the users' sleep based on how far along they are in their sleep.
            - The temperature sensors (DS18B20) will feed input to the microcontroller to ensure that the temperature that is being achieved by the blanket is consistent with the desired temperature, and it will tell the microcontroller to adjust the temperature accordingly.
        - Our control system will output 9 distinct PWM signals, one for each block of the blanket, that feed into the heating system. These PWM waves will be used to control our heating coils, which will operate at a power proportional to the duty cycle of the PWM wave it receives as an input. More will be discussed in the heating subsystem section.
        - Our control system will have an app that will be connected to the microcontroller through Bluetooth. This app will allow the user to configure the temperature they desire for each part of their sleep, as well as provide research-backed suggestions for temperatures that will help with falling asleep and waking up.
    - The control subsystem must be able to use the 9 temperature sensors and 9 IMUs to detect temperature changes (+/- 2.5 degrees Fahrenheit) and to detect movement (+/- 15% magnitude). This subsystem must be able to use these readings to generate the correct PWM signals for the heating subsystem.
- **Heating Subsystem**
    - **Overview**: The heating subsystem will be directly responsible for the majority of the functionality of our heating blanket. We plan to use a lot of the infrastructure provided by a commercially available heated blanket, such as some of the control systems. The heating subsystem will receive signals from the control subsystem and change the heat emitted by the blanket accordingly. The relay-based temperature controller will receive PWM signals, and it will react to these signals by controlling the amount of current being supplied to the heated blanket's heating supply. If the signals say to reduce the temperature or stay constant, the controller will limit the current being supplied to the blanket, and the opposite will happen if the signals say to increase the temperature.
    - **Requirements**:
        - We want our heating subsystem to be able to interpret the incoming PWM waves and to change its behavior depending on the signal. More specifically, we want the power/strength of our coils to be proportional to the duty cycle of the incoming wave. A higher duty cycle will cause our

coils to run hotter and for longer, and a lower duty cycle will cause our coils to run cooler and for shorter periods.

- Standard circuit components will be used to achieve appropriate functionality, such as using capacitors to filter out DC currents to our heating coils or using resistors to limit overall current flow. Diodes will be used to modify the direction of the AC current flow, and there will be an example of this in the tolerance analysis. In terms of the type of diode, it will be something along the lines of a 1N4007-T.
- Our heating system should be able to differentiate between any two of the 9 heating coils, allowing them to heat up or cool down independent of each other. This will mean that each one must have its own PWM signal, which will be coming from our control subsystem. The heating subsystem must be able to utilize the 9 separate PWM signals to adjust the current flowing through each coil independently.
  - Having the heating coils being powered individually is important, because otherwise it is impossible to heat all 9 subsections of our blanket to the same temperature, regardless of environmental factors. One such example would be a person sleeping in the middle of the blanket, causing the middle to heat up faster than the sides of the blanket.

Tolerance Analysis: *Note, the design in the tolerance analysis does not account for any control signals. The final circuit will be very different from the ones drawn here. These circuits are simply used to determine the type and size of the components that are to be used in our design.

Our tolerance analysis will be done on the power distribution circuit which will be used to power our heating coils. Some concerns are that adding more coils will significantly impact the functionality of our blanket, so we want to make sure that our idea is feasible.

Starting, the heated blanket we are using as an example takes in 120V AC input and operates at 110 W, meaning that the average current will be around 0.9A AC. As such, we will choose to rate all of our circuit components for a steady 1A current.

We can make an extremely simplified model for the power relay for the heating coil in our circuit shown below. In this case, we are modeling the heating coil simply as the resistive load R (since our heating coil is just taking energy and releasing it as heat into the environment).

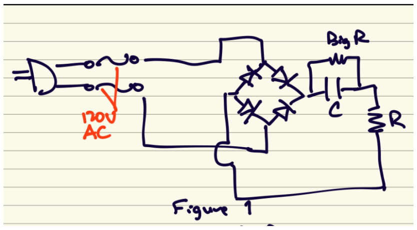


Figure 1

Notice that we have a small capacitor in series with our heating coil and a large resistor in parallel to the capacitor. This is taking advantage of the fact that capacitors let AC signals through while filtering DC signals out. This ensures that our heating coil will be running on an AC voltage, since using a DC voltage on our heating coil can have a greater risk of causing an issue.

Eventually, our goal is to have 9 heating coils replace the one larger heating coil. A naive implementation would be something like the circuits below.

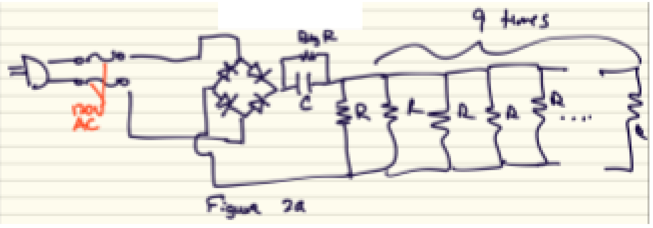


Figure 2a

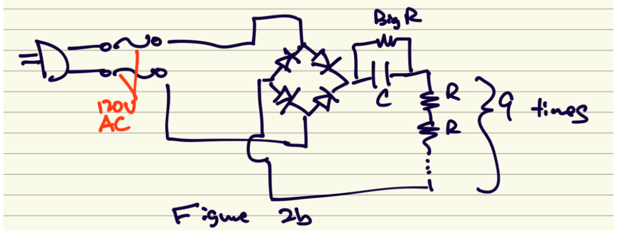
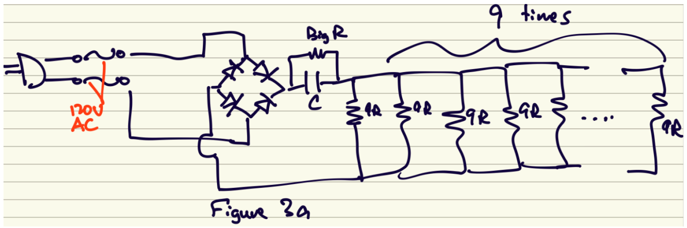
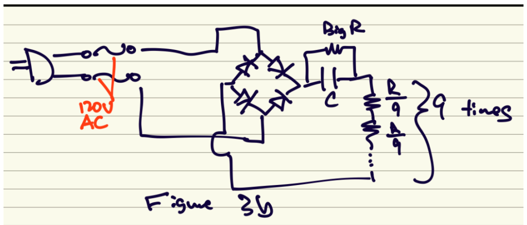


Figure 2b

But clearly this does not work. If we look at Fig. 2a, our coils have a combined resistance of R/9, meaning 9A will be flowing through our circuit, which will kill our circuit components. If we look at Fig. 2b, our coils will have a combined resistance of 9*R, which means 1/9 A will be flowing through our circuit, which means none of the coils will heat up fast enough.

Adjusting the Fig. 2 designs to get the right resistances, we get the following circuits.





This brings us to our final crossroads. We can essentially choose between really large heating coils in parallel, or really small heating coils in series. Now, if we want to keep the functionality of each of the 9 coils to be about the same as the original single coil, we have to choose the circuit in Fig. 3b. The reason is quite simple: a 90W heating coil will generate the same amount of heat as 9 separate 10W coils. However, the caveat here is that we want the coils to heat up at the same rate. The only way for the 10W and 90W coils to heat at the same rate is if there is a 9x difference in mass/size. A 10W coil that's 1/9th the size of a 90W coil will heat at the same rate.

Now, looking at the equation for resistance:

$$R = \frac{\rho L}{A}$$

R = Resistance
ρ = resistivity coefficient
L = length
A = cross sectional area

We see that a coil that is 1/9th the length must have a resistance that is 1/9th the original resistance. This is why we must choose the design in Figure 3b. If we combine all 9 resistors into 1, we see that 1A is still flowing through the heating coils. If we use the fact that V = IR, then we see that each coil is still being held at 120V AC. This satisfies all of our original requirements.

<u>Sensor Tolerance</u>: In order for our blanket to achieve proper heating and motion detection, we need to make sure that our sensors are working properly.

Firstly, we need to check if our temperature sensors are sensitive enough to satisfy our high level requirements. We intend to use the DS18B20, which is small enough to fit multiple sensors on our blanket without being too noticeable. Realistically, we do not expect to heat our blanket outside of the 60°F - 120°F (15°C - 50°C) range. The operation range for our sensors is -55°C - 125°C, which means our expected temperatures should not pose a problem for our temperature sensors. Let us assume that due to random error, or due to uneven heating, our coils end up being 5% hotter than we intend them to be. This means that our coils could reach up to 52.5°C, which is still well within the standard operation range. As such, operating temperature will likely not be an issue for our temperature sensors.

For the sensitivity of the DS18B20, it should give us measurements within +/-0.4°C of the real temperature, which translates to about +/- 1°F. This will be more than sensitive enough for us to achieve an ideal output tolerance of +/- 2.5°F.

Secondly, we need to check if our accelerometers (LSM6DSM) will work for our use case. Firstly, checking the operating temperature range, -40°C - 85°C, we see that these sensors will have no problems at the temperatures we intend to work at. Let's say we set our accelerometers at their most sensitive setting. In this case, they can measure up to +/- 2g of acceleration, or around +/- 20 m/s^2. This will cover our high level requirement of movements with acceleration exceeding 10 m/s^2 in magnitude. Our ideal output tolerance for our accelerometers will be +/- 1 m/s^2, or around +/- 0.1g. At 25°C, the datasheet tells us to expect +/- 1% tolerance in our measurements, and that this percentage will scale with our operating temperature by a rate of 0.01%/°C. At our highest operating temperature of 50°C, this should mean a tolerance of around +/- 1.25% (1 + 25*0.01), which comes out to about a +/-0.025g tolerance for our maximum linear acceleration measurements of +/- 2g. As such, these sensors will be more than sensitive enough for us to achieve an output tolerance of +/- 1 m/s^2 for our acceleration measurements at all times.

Ethics and Safety

We will move forward with this project with safety as our number one priority. As outlined in both the IEEE and ACM Code of Ethics, we need to prioritize the health and safety of our potential users and make sure to disclose any possible dangers to anybody who could reasonably be affected by the project.

Before starting any manufacturing step, we will ensure we have fully researched any potential dangers and minimized the risk. This will include testing the range of possible temperatures that are achievable by our prototypes before we have anyone personally test them. This will also include testing the quality of our circuits and circuit components. When working with electricity, we will make sure that we are following proper safety procedures to avoid accidental discharge into the environment, users, or engineers. When working with the heating elements of our project, we will take caution in avoiding incidental contact between skin and heat by wearing protective clothing during development and ensuring that any user would avoid exposure to high levels of heat.

If we suspect there may be any risk of danger to the engineers or users, or if we suspect there may be any sort of violation of procedures and regulations, we will openly communicate concerns within the team, with the course staff, and with appropriate authorities. We will make sure to thoroughly inform anyone involved with the project of any potential concerns or health risks that they might be reasonably exposed to while working on the project.

Works Cited

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[6] Demdaco, “Velvet Throw Blanket - Gray”, *demdaco.com*. [Online], Available: https://www.demdaco.com/velvet-throw-blanket-gray/. [Accessed Feb. 7, 2024].