An improvised temperature controller for a heat disinfection cabinet
by Daniel L. Marks

Rev1: March 29, 2020
Rev2: April 3, 2020
Rev3: April 13, 2020

WARNING:
These instructions are followed at your own risk.
By proceeding further, you agree to take all necessary safety precautions. In no event, should the author of this document be liable for any damages whatsoever. If you live in a jurisdiction that does not allow the exclusion of liabilities, then you should not proceed further. Because this project involves disinfection of deadly pathogens, possible electrocution from mains voltages, possible fire hazards from heating elements, and a variety of other potentially harmful and deadly risks, the author disclaims responsibility for the use of this document. This work is intended as an improvised device to disinfect PPE with dry heating in a pandemic crisis situation. Please take proper precautions around mains power and ensure that overheating does not occur. It is recommended that one read over these directions before starting the project.

Abstract: Studies have shown that the viruses on personal protective equipment (PPE), such as N95 masks, may be deactivated by the application of sufficient heat for a sufficient duration of time while preserving the function of the PPE. Successful treatment requires control of both the temperature and duration of the applied heat. This document describes an improvised heat disinfection cabinet which includes a temperature controller. The heating element is a common non-halogen incandescent light bulb, while the temperature control is construct from commonly available electrical components such as an Arduino Nano, relays, LEDs, and buttons. To construct the incandescent light heater, the constructor should be familiar with precautions taken when working with mains voltages, especially if an existing lamp is modified for this purpose.

It is recommended that one read over these directions before starting the project.

The project github which includes source code, schematics, and a PCB board layout, is located at

http://www.github.com/profdc9/SimpleTempController

Parts necessary for the temperature controller

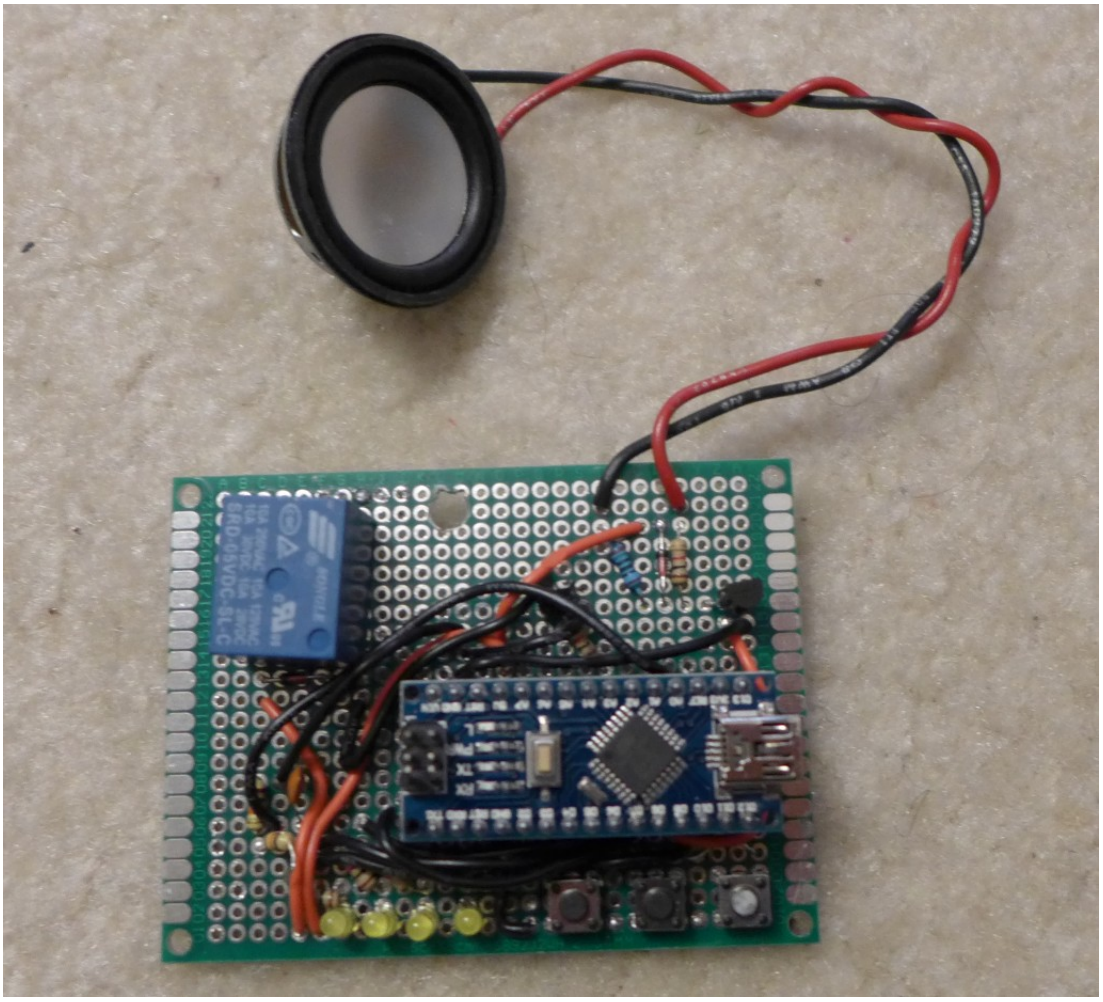
- Arduino Nano V3, Arduino Nano, or Arduino Uno
- Pin socket headers for the Arduino Nano if it is not to be soldered directly into the PCB.
- LM35 temperature sensing IC in TO-92 package
- 7 1 kΩ 1/4 watt resistor
- 1 10 kΩ 1/4 watt resistor
- 1 100 Ω 1/4 watt resistor

- 2 Small single NPN BJTs, examples: 2N2222A, 2N3904, BC548. As seen from the flat side, 2N2222A and 2N3904 have emitter, base, collector left-to-right as viewed from the flat side, while BC548 is the opposite: collector, base, emitter left-to-right as viewed from the flat side.
- 2 Small silicon diodes, examples: 1N4148, 1N4001, 1N4007, etc. The black band corresponds to the cathode, or the terminal of the diode on the schematic with the thin line (not the arrow).
- 1 100 nF ceramic disc capacitor, 25 volts
- 4 LEDs (any color)
- 3 Single pole-single throw (SPST) momentary contact (push button) normally open switch. If possible, make button #3 a different color (by selection or marking) than buttons #1 and #2. For example, make button #3 red and buttons #1 and #2 black. This is because one can simply instruct a user to turn on the device and press the red button to start the heating cycle.
- 1 Single-pole single-throw (SPST) or single-pole double throw (SPDT) 5 volt coil relay, 250 VAC voltage rated relay. Example: SONGLE SRD-05VDC-SL-C relay. A module such as shown below is better for connection because it has screw terminals but may not be available.

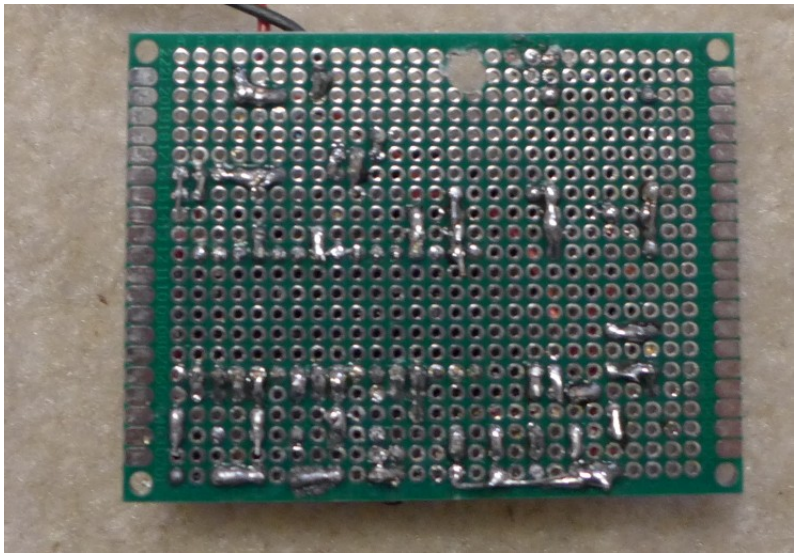
- Optional: a small piezo disc transducer or audio speaker to obtain an audible alarm.
- A 5 volt, 500 mA minimum USB power adapter with USB B/mini-B/micro-B cable to plug into the Arduino.
- A PCB, either the PCB designed by the author, or a prototyping board, solderless breadboard, or perf board as available. The PCB designed by the author is a single-layer board that can be fabricated using one-sided PCB etching.
- An insulating plastic enclosure for the PCB.

Constructing the circuit

The most likely available construction material for the PCB is a perf board. It can be constructed using point-to-point connections between the components. A solderless breadboard may be used as well, however, this has the risk that wires may become loose. The author constructed the circuit on a perf board as shown below:



Special care was taken to ensure that the relay pole, normally open, and normally closed contacts are well isolated. This is to ensure that when mains is attached to the relay, there is no accidental bridge to the coil of the relay or any other part of the circuit. There



The relay contacts are in the upper-right corner. Solder bridges between neighboring perforated hole are to be avoided at the relay contacts. A hole has been drilled through the PCB near the relay. This is to insert a cable tie which will later be used for strain relief to prevent the extension cord wires from tugging on the solder joints.

Parts necessary for the heating elements

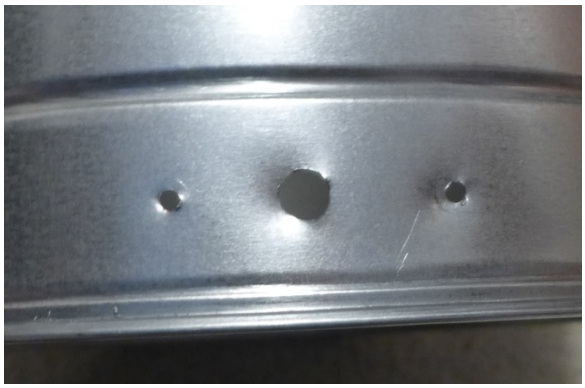
NOTE: The following procedure is probably violating all kinds of electrical codes. If you have the means of making a properly enclosed and grounded device, then you should do so. If you can get a relay module with screw terminals already connected to the relay, that is also better than soldering directly to the relay terminals as is shown here. However, we assume that this may not be possible because electronic supply services may be unavailable and relays may need to be scavenged from other equipment.

- A 3-prong extension cord (including hot, neutral, and earth ground) that will be modified.
- A metal bucket with lid as an enclosure, for example, this 6 gallon or 22 L bucket:

- Another power 3-prong power cord that is cut from a device (typically salvaged from broken equipment).
- A short length of mains hookup wire (105°C, 600 V or higher rated such as THHN)
- Two ceramic or phenolic light fixtures.
- Two 60 watt incandescent light bulbs.
- A block to mount the incandescent the light fixtures on.
- A screw, washer, and nut (M3/M4 or SAE 6-32/8-32 size).
- Cable ties and electrical tape.
- Standoffs and screws for the PCB.

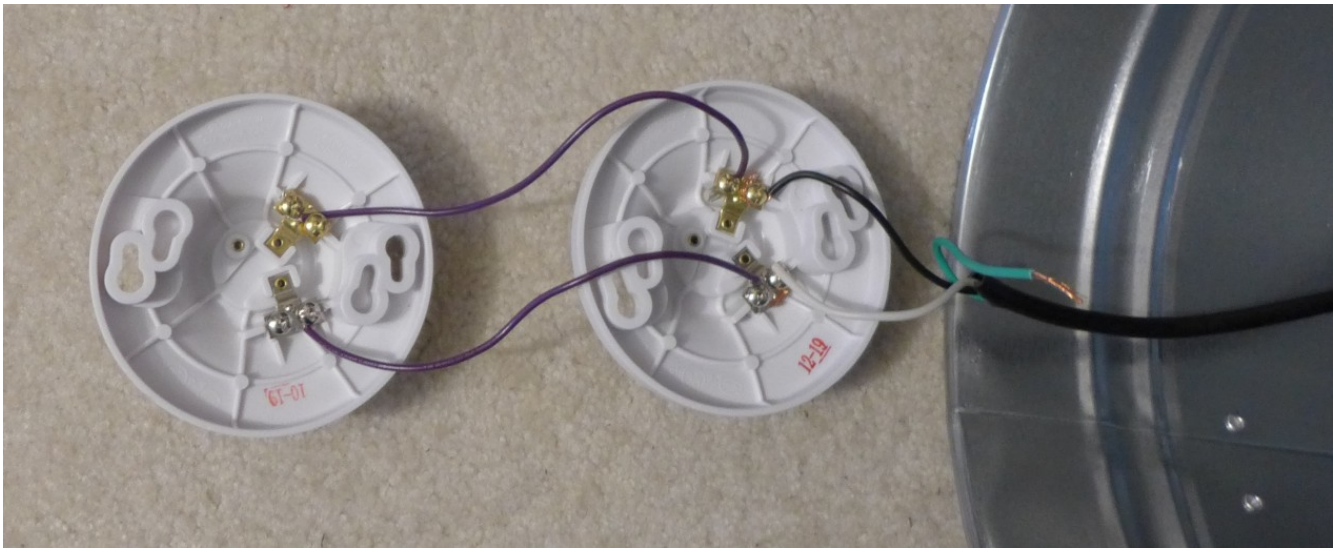
Directions:

Drill three holes in the side of the bucket near the bottom.



The larger hole is used for the power cord. One of the small holes is used for the temperature sensor, and the other small hole is used to attach a grounding lug. Insert the power cord through the hole like this:

Attach the two light sockets as shown below. The gold colored contacts on the sockets are the hot contacts, and are connected to the hot black wire. The silver colored contacts on the sockets are the neutral contacts, and are connected to the white wire. Leave the green earth ground wire unconnected presently. For European cords, the hot color is brown, the neutral color is blue, and the earth ground is yellow and green striped.



Cut a wooden block and mount the two sockets to the block as shown below. Holes are drilled into the block and the sockets are secured with wood screws.

Place the block in the bottom of the bucket and pull the cord out to take up the slack.

Where the cord enters the bucket, wrap the cord with some electric tape. This tape will serve to protect the cord from the rough edge of the metal as a makeshift strain relief.

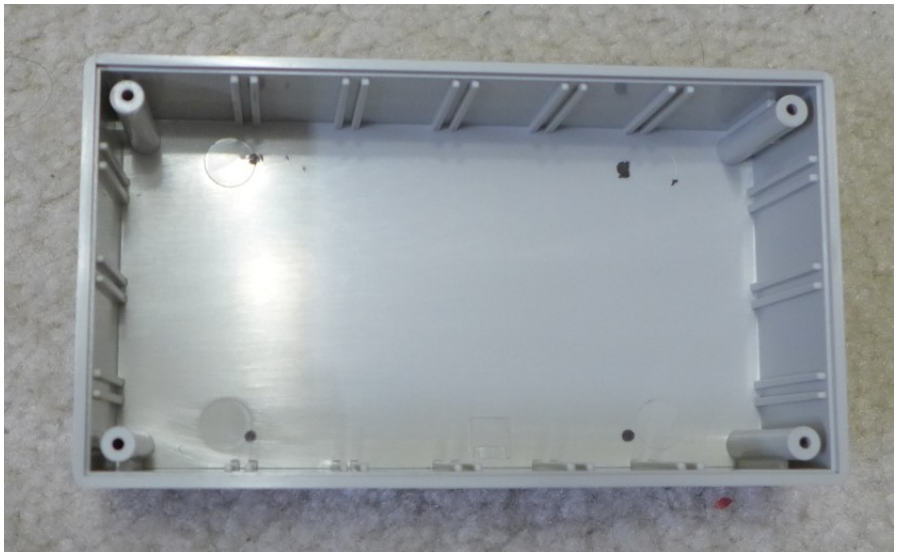
Pull the cord into the bucket so that the electrical tape is pressed up against the edges of the hole. Then tighten two cable ties as close to the wall of the bucket on either side of the cable to immobilize the cable. Cut away the excess cable tie material.

Using the screw, washer, and nut, insert the screw through a narrow hole outside the bucket. Place a washer and nut on the screw on the other side. Take the earth ground wire and curl it between the washer and the side of the bucket. Tighten the screw to clamp the earth ground wire into contact with the bucket.

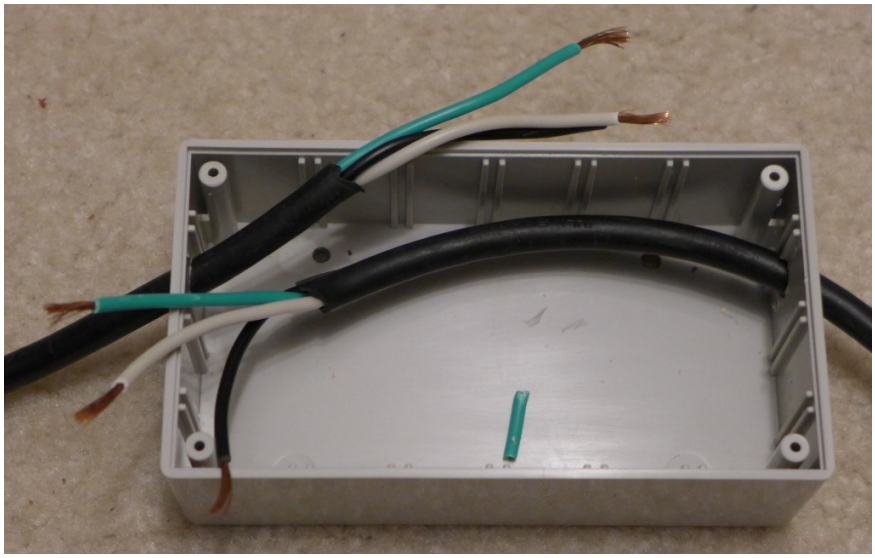
Insert light bulbs into the socket. To test the bucket, it may be plugged into the wall to see if the bulbs light.

Attaching the extension cord to the controller PCB

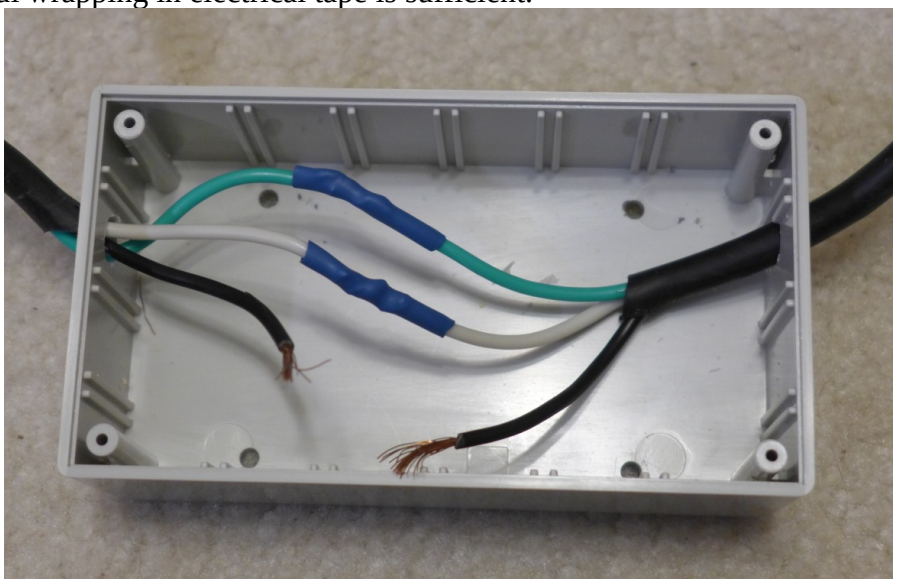
To protect the PCB and the mains connections, we place the PCB into a plastic enclosure. We first mark the positions for the standoffs on the bottom of the enclosure using the PCB as a template.



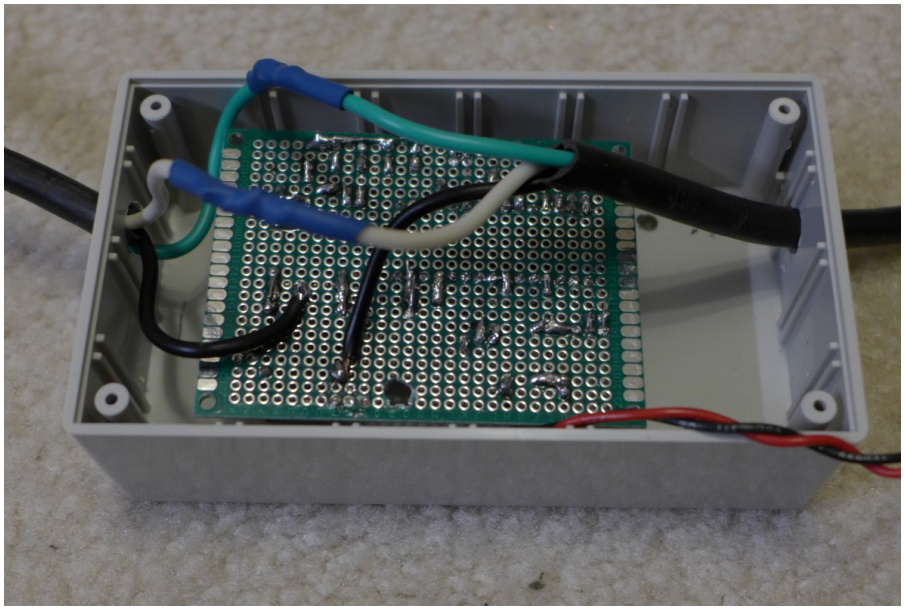
Drill holes for the standoffs and holes in the side of the box for the extension cord to enter and leave the enclosure. Cut the extension cord (after unplugging from mains!) and insert both ends into the box. Strip the insulation from the end of the wires.



Rejoin the white neutral and green earth ground wires by twisting and soldering them together. If you have heat shrink tubing, this can be placed on the wires before soldering and used to insulate the joint. Otherwise, careful wrapping in electrical tape is sufficient.

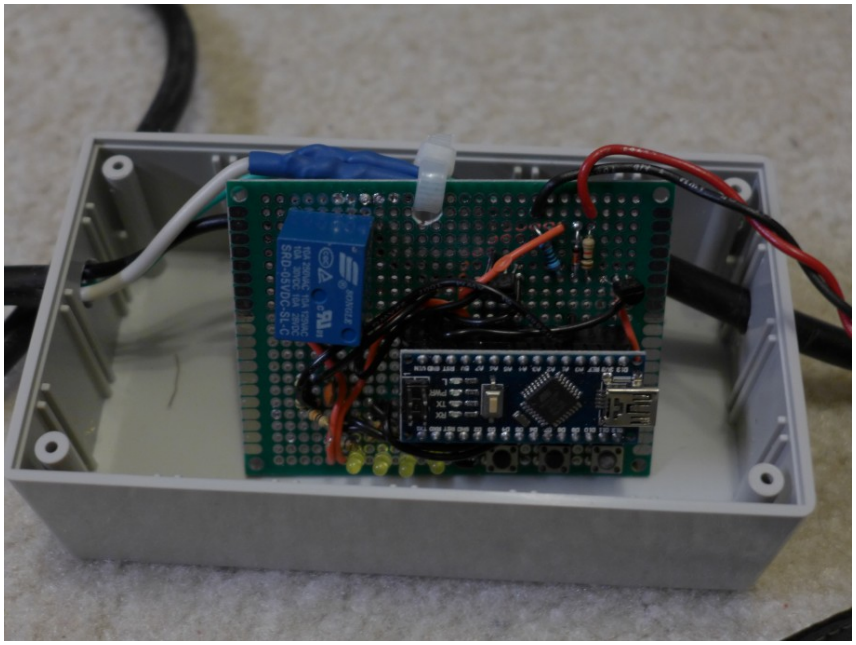


Cut the two black wires so that only a few millimeters of conduct is present. Tin the ends of the two black wires with solder as well as the normally open and pole contacts of the relay. Then join one of the black wires with the pole contact and the other black wire to the normally open contact. Make sure the black wires are oriented as to not make contact with any other parts of the circuit especially the coil contacts.

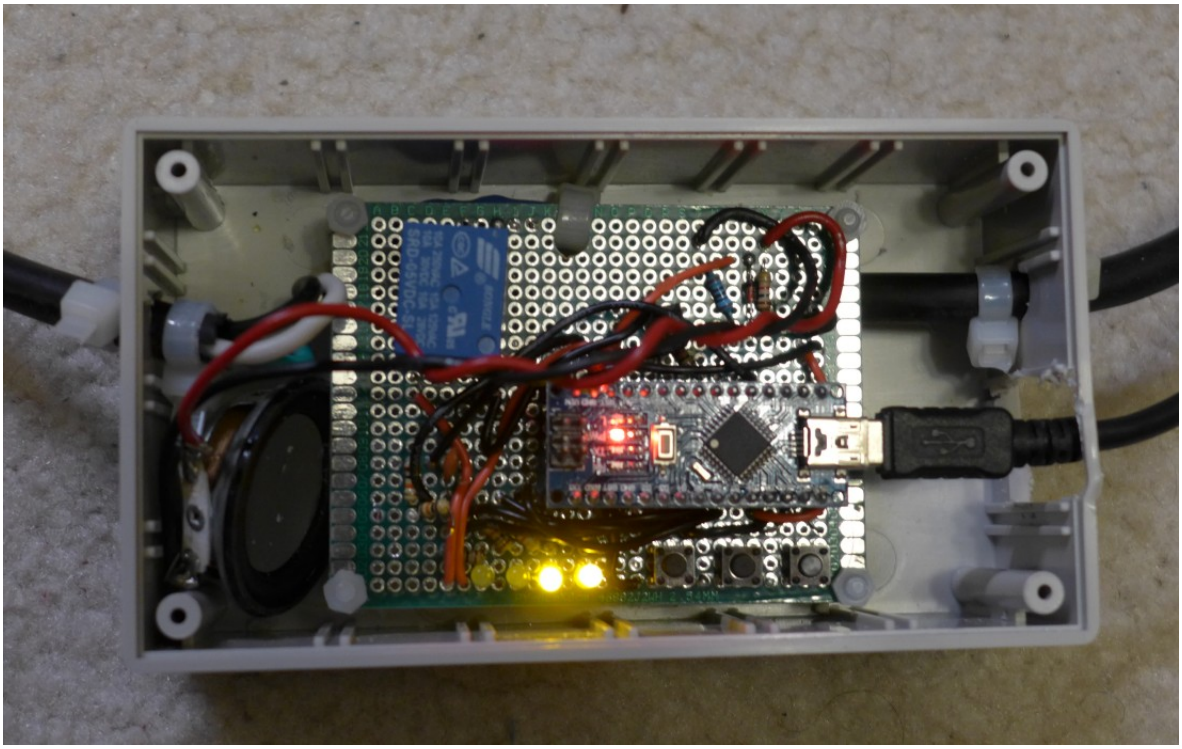


A

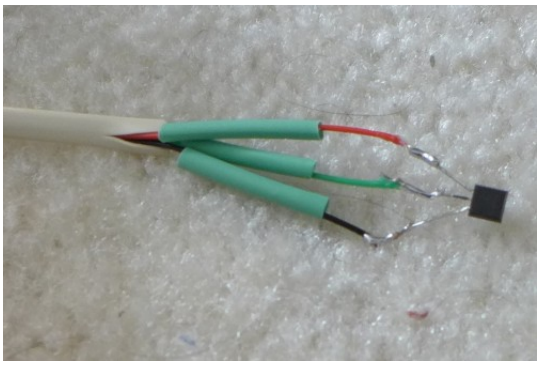
Insert a cable tie through the hole drilled in the PCB, and then fasten the cable tie around the conductor wires of the extension cord. This provides strain relief to the solder contacts to the relay.



Using a file or a rotary tool, cut a hole for the USB cable and temperature probe. Use cable ties on both sides of the extension cord where the extension cord enters and leaves the plastic enclosure to immobilize the cable and provide strain relief.



Solder the LM35 temperature module to three wires. Looking from the flat side of the LM35 IC, the leads indicate VCC, TEMP, and GND. The cable below is a four conductor cable used for connecting telephones with one conductor cut off. An ethernet cable may also be used as a multiconductor cable, as the typical ethernet cable contains four twisted pairs. Heat shrink tubing is placed over the wires if available to insulate the connections from each other, or electrical tape is used if not available.



Heat shrink tubing is applied over all of the temperature probe wires to bind them together, or alternatively electrical tape is wrapped around all of the wires.

Place the probe in the bucket and feed the end of the wire through the bucket. Position the probe at the bottom of the bucket, preferably in the shadow of the block to minimze direct illumination of the probe. Solder the three wires to the appropriate places on the PCB for power, ground, and the temperature connection as shown in the schematic. Use a cable tie to affix the temperature probe wires to the extension cord to strain relief the wires so that the solder joints on the PCB are not tugged on by the temperature probe wires. Mount the PCB to the case using the standoffs.

To assemble the system, plug the light bulb heaters into the end of the extension cord, the extension cord into mains power, and the USB power adapter into the Arduino.

Programming the Software

The software is a single file Arduino project. The Arduino programming environment should be installed on your computer. When plugged into a computer, the Arduino appears as a COM or serial port. This COM port should be selected in the Arduino environment. Furthermore, the board selected should be “Arduino Nano” and the processor is “ATMega328P.” Note that if your Arduino Nano uses the CH340G serial chip rather than the standard FTDI-based chip, the “ATMega328P (Old Bootloader)” option should be selected instead. Load the Arduino project and select “Upload.” The project should be compiled and uploaded to the processor, and the processor will execute the software, flashing the code

■ ■ □ □ □ □ ■ ■

if successful.

Using the temperature controller

The temperature has three buttons and four LEDs that indicate the state of the controller. The interface is intentionally kept basic and constructable from simple parts. The three buttons are referred to by the numbers #1, #2, and #3. The state of the four LEDs are shown in the following way:

■ Filled square indicates LED is on
□ Empty square indicates LED is off

■□■□ The four LEDs are in the pattern on, off, on, off.

To avoid confusion, the mirror image of the four LED pattern is never used to indicate a different state, so for example

■□■□ and □■□■

are the same indication.

When the controller is first turned on, the following pattern is flashed on the display:

■■□□ □□■■

At this point, one can select three options:

- Select the temperature by pressing and holding button #1 for five seconds. The display will flicker while the button is held.
- Select the duration of the cycle by pressing and holding button #2 for five seconds. The display will flicker while the button is held.
- Start the heating cycle by pressing and holding button #3 for one-half second. The display will flicker while the button is held.

If the device has no configuration, the default is 70°C temperature, 30 minutes heating cycle, and 2°C hysteresis.

Selecting the temperature:

Selecting the temperature is first initiated by pressing and holding button #1 for **five seconds** when the controller is flashing the code ■■□□/□□■■. The following sequence cycles several times on the display to show that the temperature set point option is selected:

■□□□ □■□□ □□■□ □□□■

A code then flashes on the LEDs to indicate the selected temperature. By pressing **button #2**, one may cycle through the options for temperature. By pressing **button #1**, the temperature is selected.

■□□□ 60°C □■□□ 65°C

■■□□ 70°C ■□■□ 75°C
■□□■ 80°C ■■□■ 90°C
■■■■ 100°C

Selecting the duration:

Selecting the duration for which the heat is maintained at the target temperature is first initiated by pressing and holding **button #2** for **five seconds** when the controller is flashing the code ■■□□/□□■■. The following sequence cycles several times on the display to show that the duration set option is selected:

■□□■ □■■□

A code then flashes on the LEDs to indicate the selected temperature. By pressing **button #2**, one may cycle through the options for temperature. By pressing **button #1**, the temperature is selected.

■□□□ 10 minutes □■□□ 20 minutes
■■□□ 30 minutes ■□■□ 45 minutes
■□□■ 60 minutes ■■□■ 90 minutes
■■■■ 120 minutes

Selecting the hysteresis temperature:

In some cases, the controller may cycle rapidly between turning the heating element on and off while in the heating cycle. This is because the controller is responding too quickly to changes in temperature. To prevent this, the hysteresis of the controller is adjustable. The hysteresis setting determines the temperatures the controller turns the heating element on and off. For a given hysteresis temperature, the controller turns off the element when the temperature is over the set point by the hysteresis temperature, and turns back on the element when the temperature is below the sent point by the hysteresis temperature. For example, if the hysteresis temperature is 4°C, and the set point is 70°C, the heating element is turned off when the temperature exceeds 74°C, and the heating element is turned on when the temperature is below 66°C.

To select the hysteresis, first press and hold **button #1** for **five seconds** when the controller is flashing the code ■■□□/□□■■ as if the temperature is being changed. The following sequence cycles several times on the display to show that this temperature set point option is selected:

■□□□ □■□□ □□■□ □□□■

The mode to select the target temperature is entered. Next, press and hold **button #3** for **five seconds**. Then the following sequence cycles several times on the display to show that the hysteresis set point option is selected:

■□□□ □□□■ □■□□ □□■□

A code then flashes on the LEDs to indicate the selected hysteresis temperature. By pressing **button #2**, one may cycle through the options for hysteresis temperature. By pressing **button #1**, the hysteresis temperature is selected.

■□□□	1°C	□■□□	2°C
■■□□	3°C	■□■□	4°C
■□□■	5°C	■■□■	6°C
■■■■	7°C		

Staring the heating cycle:

Before starting the heating cycle, the heating element, temperature sensor, and object to the disinfected should be placed into the enclosure and the enclosure closed. To initiate the disinfection cycle, press and hold **button #3** for **one-half second** when the controller is flashing the code ■■□□/□□■■.

The initial heating part of the cycle will begin. The heating element will turn on and continues until the temperature reaches the target temperature. This is indicated on the LEDs by the following alternating pattern:

■□■□ □■□■

The time required to reach the target temperature depends on the heating element power, the size of the enclosure, how well the enclosure is insulated, and the target temperature. Once the target temperature is reached, the second part of the heating cycle initiated. The temperature is held at the selected target temperature for the selected duration. During this cycle, the following codes are shown on the LEDs:

■□□□	Code during the first quarter of the cycle duration.
■■□□	Code during the second quarter of the cycle duration.
■□■□	Code during the third quarter of the cycle duration.
■□□■	Code during the last quarter of the cycle duration.

If the heating element is presently on, the rightmost LED is flashing, otherwise it remains constantly on. Once the second part of the heating cycle is completed, the entire cycle is completed and the heating element is turned off, and the following code is flashed:

■■■■ □□□□

Pressing any of the buttons ends the cycle. Any time during the cycle, **button #1** may be pressed and held for **one second** to terminate the cycle prematurely.

If there is a problem during the heating cycle, the heating cycle is terminated, the heating element is turned off, the following error code is flashed:

■□□■ □□□□

Any of the three buttons can be pressed to clear the error code. The error can occur for the following reasons:

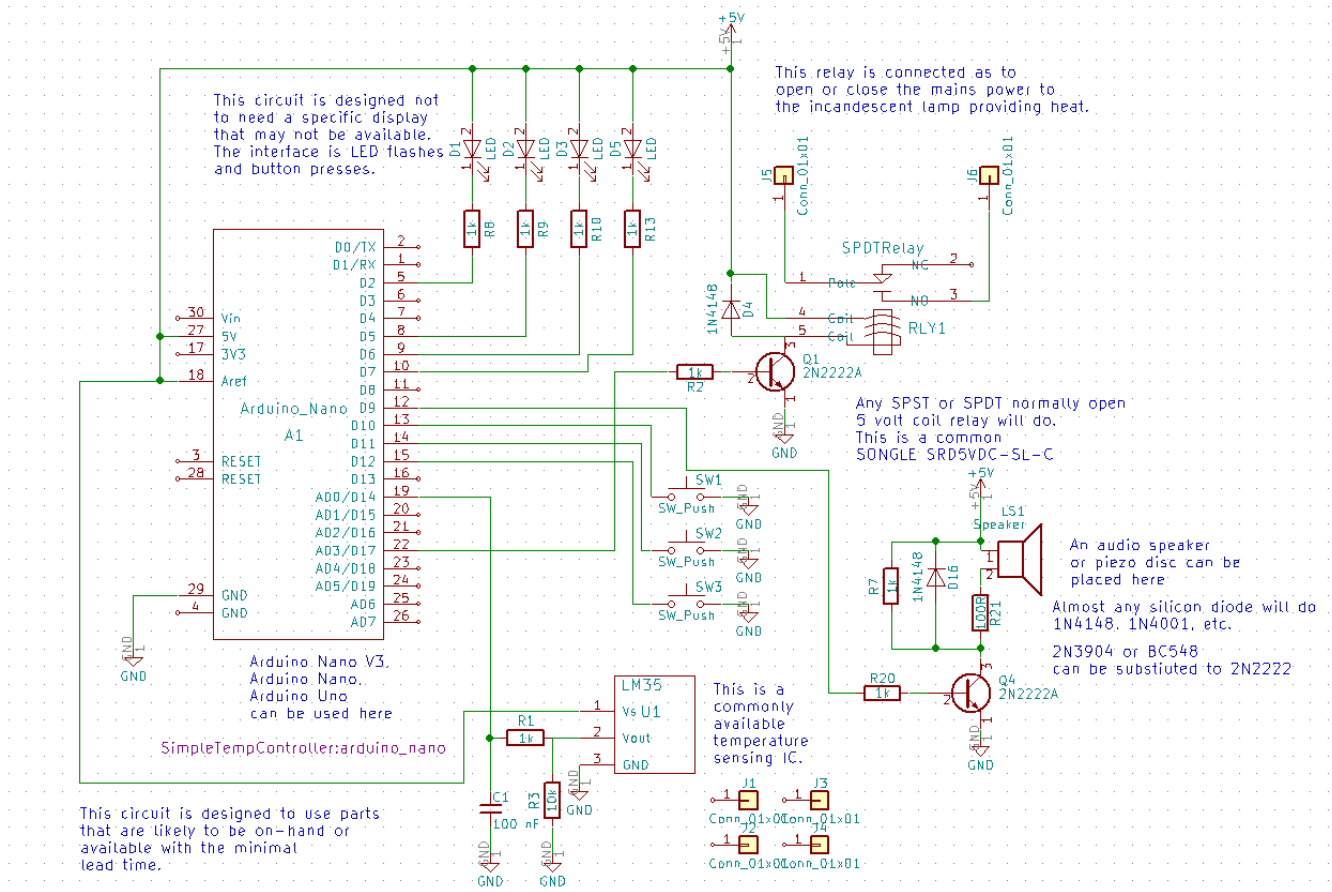
- The temperature probe is faulty or is detecting an invalid temperature, which is either below 2°C or above 200°C.
- During the initial part of the heating cycle, a temperature more than 10°C higher than the target temperature is measured.
- During the second part of the heating cycle, a temperature more than 10°C higher than the target temperature, or less than 10°C below the target temperature, is measured.

In case of this error, check the following conditions, powering off the temperature controller and heating element first and disconnecting them/unplugging from mains power:

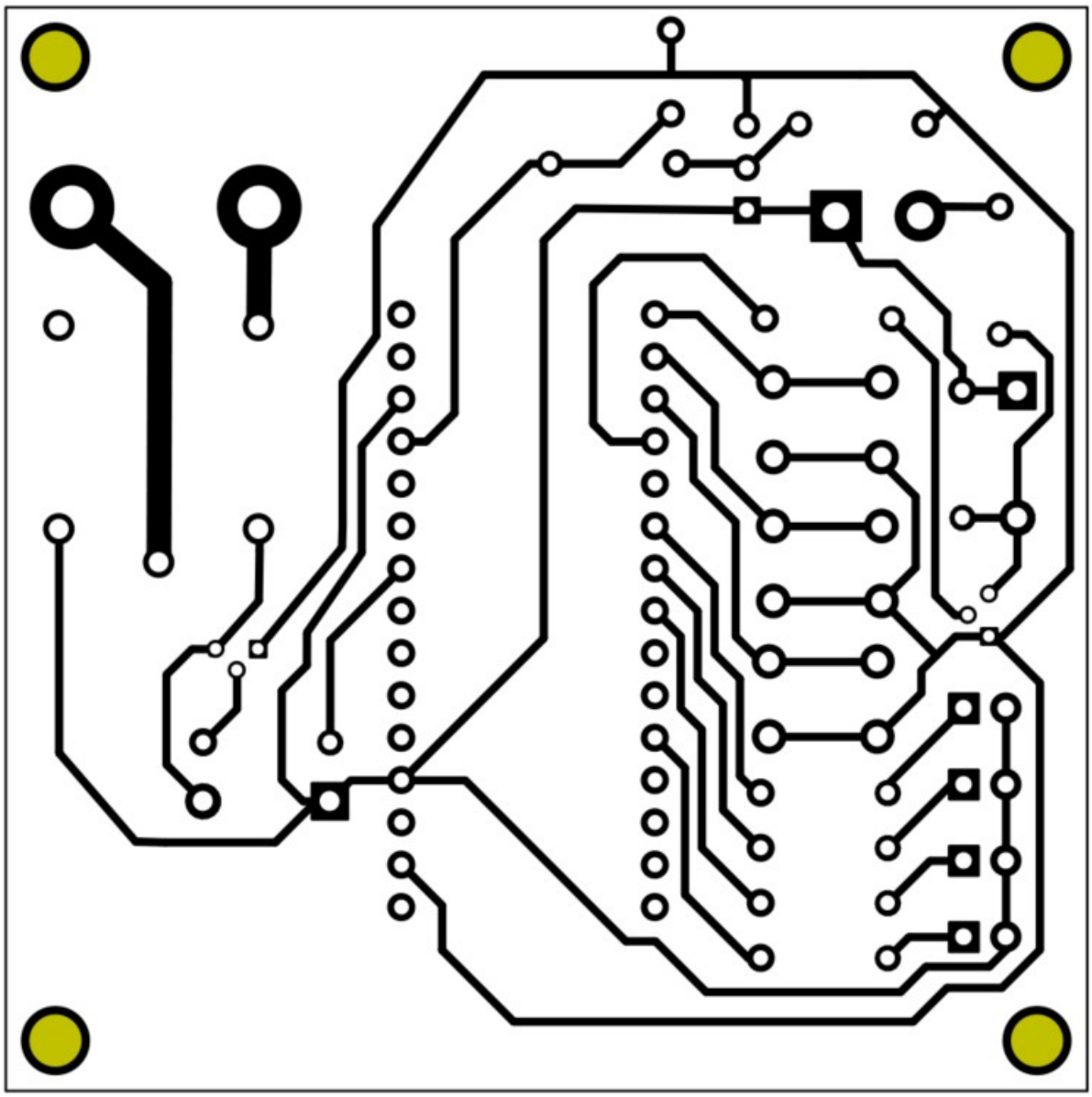
- Ensure that all three wires (power, ground, and temperature signal) to the LM35 integrated circuit are connected. Measure the voltages of these signals both at the sensor and the controller, with the heating element disconnected from power, to ensure the connection is based.
- Ensure that the heating element is turning on during the initial cycle, that the incandescent bulb is not burned out, and that the power switch is on to the lamp (if present).
- Ensure that all soldered and/or wire nut connections are secure.
- Ensure there is no damage to the heating element or lamp that could indicate burning of the insulation on the wires or a short circuit of the wires.
- Inspect the enclosure for any signs of damage, especially around the heating element that could indicate excessive heat, charring, or pyrolysis.

Because this is an improvised enclosure using a heating element, the enclosure should be monitored, especially when it is first being used, to ensure that the enclosure or its contents are not damaged by the heating.

Appendix A. Circuit schematics



Appendix B. Single Layer PCB Layout



The dimensions of the board are 65 mm by 65 mm.

Appendix C. PCB appearance and component placement