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Building The Ultimate Dew Shield

A home brew dew shield with automatic temperature control

Cheng-Yang Tan

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I've always found it interesting that, we amateur astronomers are willing to spend hundreds, if not, thousands of dollars on optics, mounts, cameras, programs for imaging and processing but scrimp on some of the most basic stuff like dew shields. One of my friends, (who shall remain anonymous), is an avid cataloger of variable stars. He owns expensive equipment for automatic imaging and cataloging, however, when it comes to keeping dew off his equipment, his advice to me was to "buy a heated blanket from (name your favorite superstore) and wrap it around the scope". To each their own, I guess. A quick search on the web yields the same type of sage advice — buy a yoga mat, or thin foam insulation, or a cardboard tube and cut it up to fit your scope. And if you want to get fancy, you can buy an Astrozap [1] dew heater and wrap it around the scope or around the dew shield as well. Of course, I have also found commercial dew shields and heater controllers made by Astrozap, Dew-not [2], and Kendrick Instruments [3]. I'm sure they all work, but after reading through their specifications, and in the spirit of "scrimping", I came to the conclusion that I can make a better dew shield and controller for less money. (Well, maybe not, in the end ☺).

The dew shield

The first thing before I build the dew shield is to understand why a dew shield works in the first place. A dew shield is able to keep the telescope objective free of dew because it contains a warmer column of air than ambient, which is hopefully above the dew point in front of it. Therefore, it is imperative to stop this warm air from cooling off, or escaping. A well-designed dew shield has to have an insulation layer between its inner part and its outer part. It's even more important to have insulation for a heated dew shield because I want to heat the air inside and not try to heat up Mother Earth. Furthermore, its outer color has to be reflective and not black to reduce radiative cooling. This is usually the first design flaw in most amateur (and dare I say, commercial products too) designed shields where their outer color is usually not white or silver.

Therefore, from the above analysis, my basic requirements for the dew shield are to have insulation between the inside and outside and a reflective outer shell. My design (inspired by T.J. Nelson [4]) consists of two shells of aluminum flashing and 1/8″ self-sticking duct insulation, which has an R-value of 3, sandwiched between the two shells. See Fig. 1. I also stuck on 4 heat pads (available from Sparkfun [5]) onto the inner aluminum shell where I had made a mark about 1″ from the edge of the optical assembly after the dew shield is installed. I wired the heat pads in parallel before sticking on the insulation (Fig. 1(b)). The outer shell is wrapped around the insulation and the inner and outer shells are riveted together so that they become one unit. The gaps between the two shells are filled with black latex caulk (Fig. 1(d)) so that after the caulk dries and cures, the entire structure still remains flexible. For the inner shell, I stuck on self sticking black felt [6] that not only flocked it but also filled in the gaps between the dew shield and the telescope (Fig. 1(e) and (f)). Finally, I stuck on Velcro strips to hold the dew shield in place on the telescope (Fig. 1(g)). I think the result looks pretty professional despite having spent less than $50 in parts to build this.

The as-built dew shield, even without heating, is already an improvement over my previous dew shield that was made of cardboard and cork. However, the *coup de grace* is when the automatic temperature control is added. But before I discuss the temperature controller, I have to do two temperature measurements.

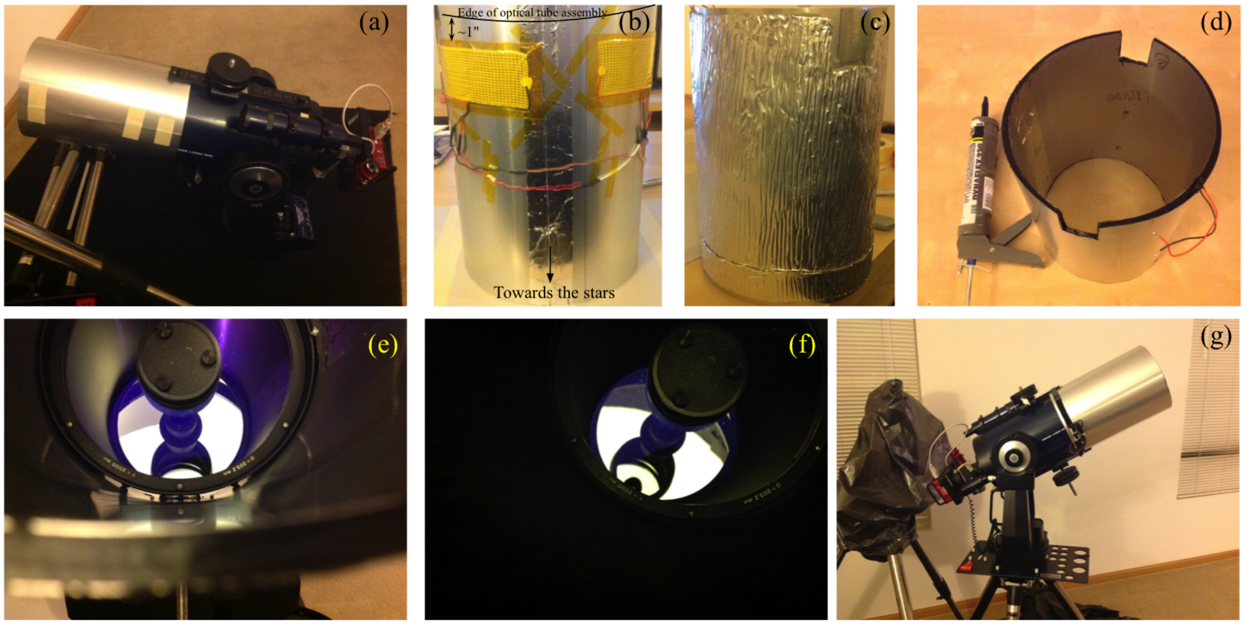

Fig. 1: (a) A piece of 14″ long aluminum flashing is wrapped and its edges taped around my 8″ optical assembly after it is cut and fitted. (b) The edges of the flashing are taped together with aluminum foil tape and heat pads are wired in parallel and stuck to the flashing with kapton tape. (c) The entire surface is insulated with 1/8″ self-sticking duct insulation. (d) Another aluminum flashing is wrapped around the insulation to form an outer shell. The inner shell, insulation and outer shell are riveted together to form one unit. Black latex caulk is used to fill the gaps. (e) There are gaps between the inner shell and the optical assembly that needs to be filled in. (f) Self sticking black felt is used to fill in the gap and to act as flocking. (g) The assembled dew shield is slid onto optical tube assembly and held in place with velcro.

Temperature measurements

There are two measurements that I have to do before I can design and build the automatic temperature controller. The first measurement is the temperature profile of the dew shield when it is heated to steady state so that I can determine where to mount the temperature probes for measuring the internal and ambient temperatures. The other measurement is to see how the temperature responds when the heater is suddenly turned on. I will discuss these two measurements below.

Steady state temperatures

I can measure the steady state temperature of the heated dew shield when I power it with DC voltage. I use a 5 V, 3 A power supply to power the heaters because the recommended maximum voltage for the heat pads is 5 V. I can calculate the required current by measuring the resistance of the 4 heat pads in parallel, which is 2.5Ω, and by applying Ohm's law, I find that I need 2 A. Therefore, the power supply that I will use is more than adequate.

After turning on the power to the heat pads, I waited for an hour before starting my measurement. My friend, J. Larson, and I measured the temperature profile with a thermal imager. The results of several measurements at different locations are shown in Fig. 2. It is not surprising that the highest measured temperature is at the heat pad and there is a clear variation in temperature along the azimuth of the dew shield at the heat pad level which can be as much as 4°C. Hence, this is not a good location for me to place a temperature probe to measure the internal air temperature. However, the temperature variation azimuthally along the felt, right on the edge of the telescope end is about 1°C and thus, I decided that this is the best location for me to place the temperature probe for measuring the internal air temperature. The location for placing the probe for measuring ambient temperature is clearly at the open end of the dew shield, i.e. it needs to be as far away from the heat pads as possible.

Thus, from these measurements, I have determined the best locations for placing the temperature probes and in the next measurement I will measure the temperature response of the system when the heater is suddenly turned on. This is called the "step response" of the system and is needed for calculating the parameters of the temperature control loop.

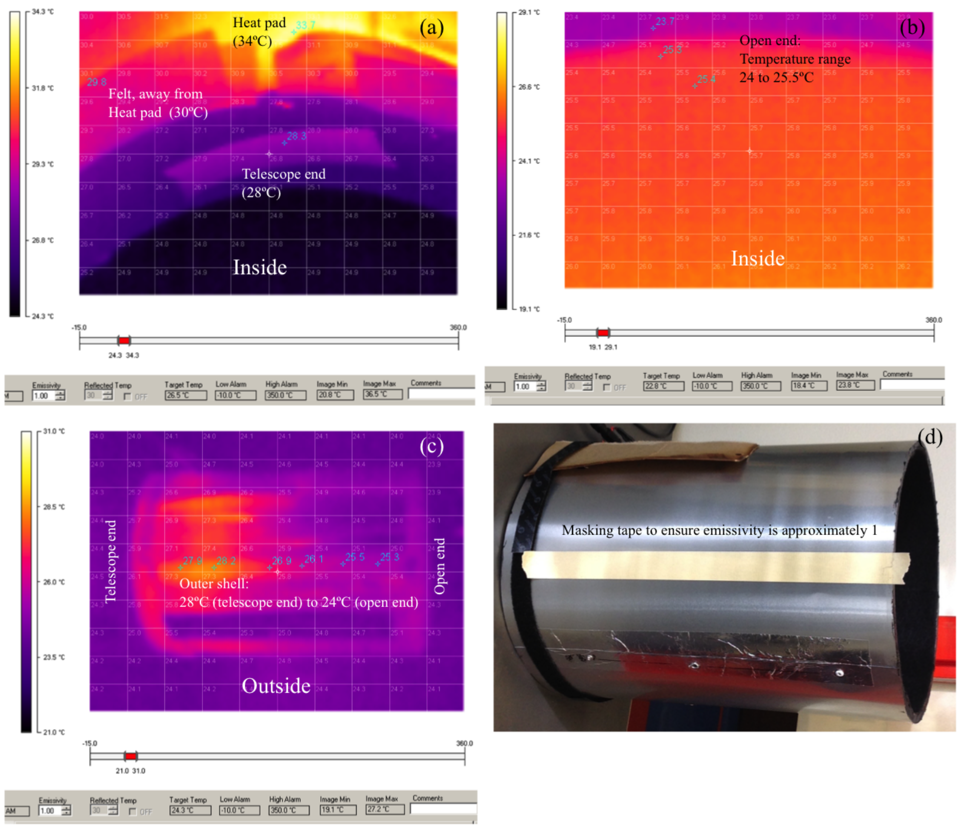

Fig. 2: The temperature profile of the dew shield at steady state. (a) Not too surprisingly, I measured the highest temperature on the heat pad at 34°C. The temperature just above the telescope end is 30°C. (b) The coldest temperature is at the open end at 24°C. (c) On the outer shell, the temperature ranges from 28°C at the telescope end to 25°C at the open end. (d) I used masking tape to ensure that the emissivity of the surface is approximately 1 for an accurate temperature measurement.

Step response

For the step response, I jerry-rigged up two temperature probes (A and B) and connected them to a small Arduino [7] micro-controller called the Arduino Pro Micro [8]. Arduino is an open source controller that has a large ecosystem of hardware peripherals that is extremely easy to setup and use. One peripheral that is available is a digital temperature sensor DS18B20 [9] made by Maxim Integrated that I use in my jerry-rigged temperature measurement (which I will also use in the final design) setup shown in Fig. 3. The measurement of the step response for both heating and cooling is shown in Fig. 3(d) and (e). As you can see, it takes a while for the temperature difference between the two probes to attain steady state in both cases. Exponential fits to the data show that the time constant for heating is about 450 seconds and cooling is about 200 seconds, which are quite long. These long time constants will affect my decision on the type of control loop that will be used to control the temperature. I will discuss the types of control in the next section.

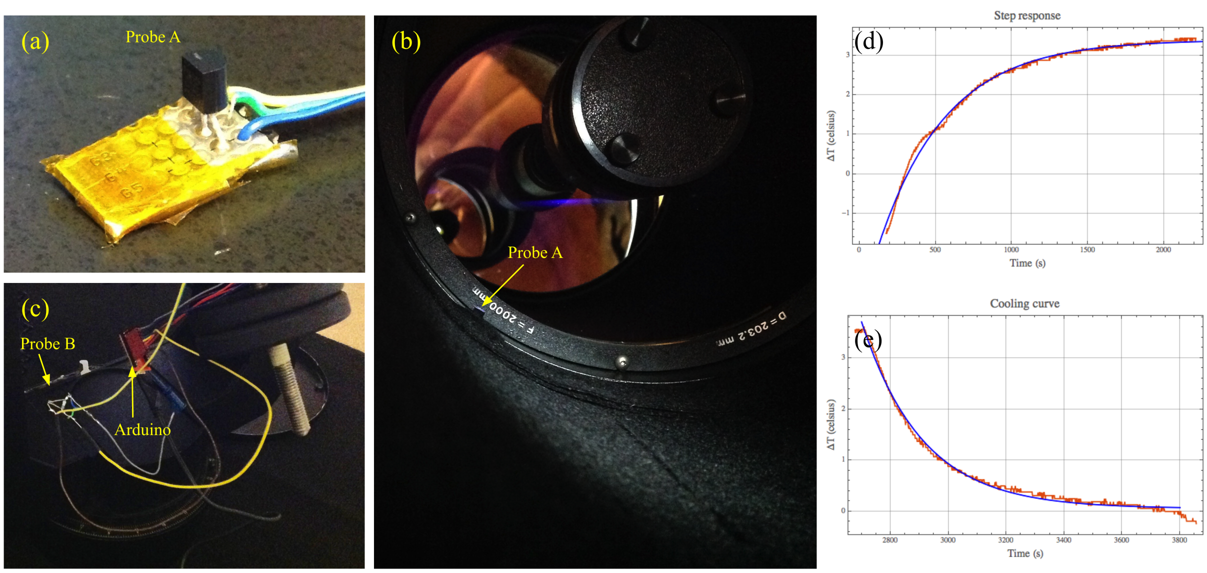

Fig. 3: (a) One of the temperature probes is mounted on a perf board and (b) installed just under the felt and close to the telescope. Probe A does not cause any vignetting because it does not block the aperture. (c) The other temperature, probe B, measures the ambient temperature. The Arduino micro-controller connects to probes A and B and to a Mac via a USB serial line. (d, e) are the step responses of the system for both heating the cooling. The measured data is shown in red and the exponential fit to calculate the time constants in each case shown in blue.

Choice of control loop

For temperature control, there are usually two types of control loops that most people consider: a proportional loop (P) or a proportional-integral (PI). [10] These two types of control loops are shown in Fig. 4. In this figure, when $K_i = 0$, I have a P loop. In P loops, the size of the correction is proportional to ΔT, which is the temperature difference between the sum of the reference temperature and the user setting (($T_{\rm ref} + dT_{\rm set}$) in this instance) and the temperature inside the dew shield ($T_{\rm inside}$). This is the simplest type of control loop, but P loops suffer from its general inability to get $T_{\rm inside}$ to eventually converge to ($T_{\rm ref} + dT_{\rm set}$) no matter how long it tries to correct it. You can see this property in the inset of the P graph in Fig. 5 for different gain values of K_p.

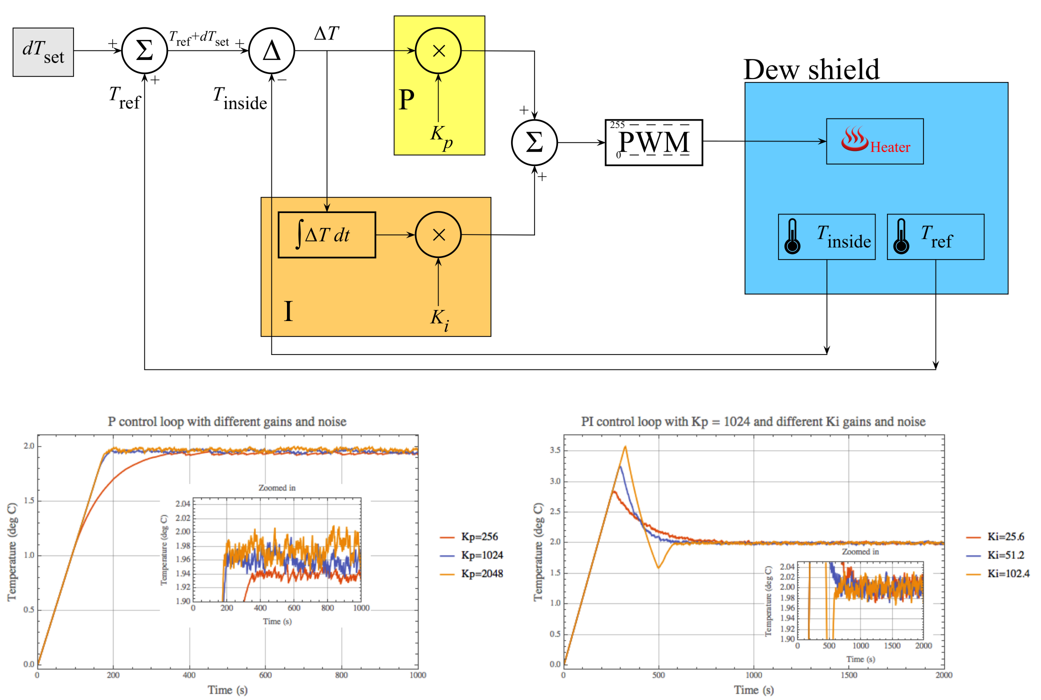

Fig. 4: The temperature control loops. The simulations look at the step responses of the P and PI loops for different gains. The goal of these step responses is for the loops to converge to $T_{\rm ref} + dT_{\rm set} = 2$. $T_{\rm ref}$ is either the ambient temperature or the dew point temperature. The P loop generally fails to accomplish this goal, but the final result is quite close to "2". The PI does eventually converge to "2" but it does have the disadvantage of overshooting it at the start.

For $T_{\rm inside}$ to eventually converge to the desired ($T_{\rm ref} + dT_{\rm set}$), it is necessary for me to introduce the integration block I into the control loop shown in Fig. 4 by setting K_i to a non-zero value. With the addition of the integration block, I get a PI control loop. The integrator essentially sums all the ΔT's over time and eventually, if I have set the gain K_i correctly, this sum goes to zero. PI loops have the property that it will eventually converge to ($T_{\rm ref} + dT_{\rm set}$), or $\Delta T = 0$ *if* the gain K_i is set correctly. But the price that I have to pay is that it will overshoot ($T_{\rm ref} + dT_{\rm set}$) at the beginning. For example, from the inset of the PI loop graph for $K_p = 1024$ and various values of K_i, you can see that the larger K_i is, the larger the overshoot is at the beginning. However, if K_i is too large, the loop becomes unstable and theoretically T_{inside} can go to infinity!

In order to arrive at my decision between these two loop choices, I took the heating and cooling step responses shown in Fig. 3 and wrote a simulation to see the difference in performance between the P and PI loops. For a more realistic simulation, I added white noise to the least significant bit of the temperature read back. This white noise is to mimic the noise seen in the heating and cooling step responses. I will not go into details of my simulation in this article, but you can find my in depth discussion about it in [11]. After I performed the simulation and looked at the results shown in Fig. 4, I decided that the P loop is good enough for my purpose because although $\Delta T \neq 0$, it is less than 0.5°C which is the accuracy of the temperature probes. Furthermore, I do not like the overshoot in the PI loop because it takes a long time for it to cool down. Therefore, I will only use the P loop in the implementation that I will discuss in a later section.

Temperature goal

My goal for the temperature controller is to be able to measure both the ambient temperature, i.e. the temperature outside the dew shield T_{outside}, and the dew point T_{dewpoint}. Once I determine these two temperatures, I can set an offset temperature dT_{set} of my choosing so that the temperature inside the dew shield is always given by the following equation:

$$\begin{aligned} T_{\text{inside}} &= \begin{cases} T_{\text{outside}} + dT_{\text{set}} & \text{if } T_{\text{outside}} > T_{\text{dewpoint}} \\ T_{\text{dewpoint}} + dT_{\text{set}} & \text{if } T_{\text{outside}} < T_{\text{dewpoint}} \end{cases} \\ &\equiv T_{\text{ref}} + dT_{\text{set}} \end{aligned} \tag{1}$$

The above equation will always ensure that T_{inside} is always above the dew point because the value of T_{ref} is always the larger of T_{outside} and T_{dewpoint}. OK, since I have what the P loop needs to do I can start work building the controller.

The control hardware

The control hardware is based around the Arduino Pro Micro that I had used earlier. This time around, however, I have added a relative humidity sensor, the HIH4030, [12] and a nice graphics display [13] to show the settings and the dynamical parameters that are interesting to me. I need to have the relative humidity sensor because the dew point is calculated from the relative humidity and the ambient temperature. I can set the offset temperature dT_{set} using a pot on the controller, which my program reads to set up the P loop. The controller, dew shield and my LX200 set up for a night of photography is shown in Fig. 6.

Performance

Once the P loop takes over, the heaters on the dew shield are heated via the method of pulse width modulation (PWM, see Fig. 4 and [14]) and the temperature inside the dew shield eventually gets to where I want it to be. The plot in Fig. 6 shows the performance of the temperature controller compared to my model of its theoretical performance that I have used in section “Choice of control loop”. As you can see, its performance is what is predicted by my model and the loop error is less than 0.5°C that I require! Not too bad!

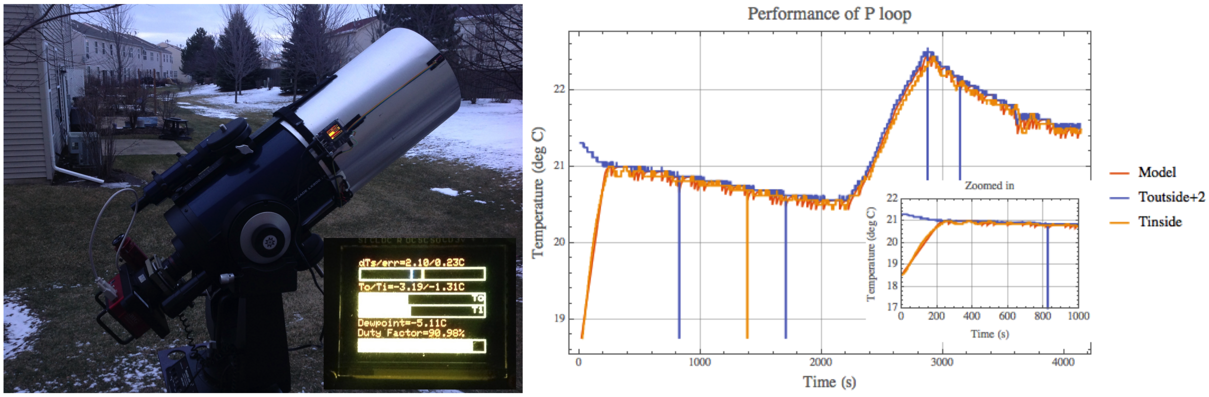

Fig. 6: My telescope set up and cooling down in the backyard for a night of astrophotography. (A home built field derotator [15] allows astrophotography with an alt-az mount). The inset shows the temperature later that night. The loop error is $(0.23 < 0.5)$°C which is within my design requirements. And the dew point is only 2°C below the ambient temperature that night. On the right is a plot of the measured performance of the temperature control loop with $dT_{\text{set}} = 2$°C compared to my simulation. As you can see, my model matches the measurement very well.

Conclusion

At this point, I think the dew shield and controller design is very nice. It performs very well and I have not had any dew problem since. On the cost side, it is a little more expensive than a commercial dew shield and controller. My estimate for the cost of one dew shield and controller is about $300. It doesn't break the bank but it's definitely not as cheap as a heated blanket. As a service to the amateur community, I have released the complete hardware design and software program as open source and can be downloaded from [16]. Have fun building one!

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