Don’t let the RAT bite you!

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ABSTRACT

We all know how important emissivity is for infrared temperature measurement. But emissivity is really just one side of the coin. The other factor is one with many names, most of them widely misunderstood! The terminology has not been very clear, and we have been fighting with this for years.

The factor I am referring to is the one that has been called T-ambient, T-background, and perhaps a few other names too. The trouble with the terminology so far is that it has been misleading. This factor is not the temperature of the air around the target, or the camera, or the temperature of the objects behind the operator, or behind the target. In fact, it is not even a true temperature!

The main point is not what we call it, but that we know what it is. In an effort to clarify the terminology issue, all new FLIR cameras and literature, and all new ITC literature, will use a new set of terminology, beginning this year. The full name of this correction factor will be "reflected apparent temperature". In the cameras, the factor will be abbreviated T_{refl}. If you want a simple rule of thumb, you could use the abbreviation RAT, if you don't think it is too distasteful. (Anyway, RAT is what it will turn out to, whether we like it or not, because any other order of the words would make it confusing again!)

In this paper, I will explore some of the misunderstandings that have existed, and why they are incorrect. Then I will go on and explain the components of the term, one by one. What does "reflected" mean, and what is "apparent temperature". Finally, we will take a good look at what could happen if you let the RAT bite you. And believe me, under some circumstances, it can certainly hurt if you do!

Keywords: Infrared temperature measurement, T-ambient, background reflected temperature, emissivity, reflections, reflected apparent temperature, T_{refl}, definitions, terminology, object parameters, measurement accuracy

1. THE INFRARED TEMPERATURE MEASUREMENT SITUATION

If we want to measure temperature with infrared instruments, a number of conditions must be fulfilled. Those conditions can be summarized as follows:

- The instrument must be calibrated.
- The target is located in an atmosphere, usually air that is highly transmissive to the infrared wavelength our instrument is using.
- The target must be opaque to the infrared wavelength our instrument is using (i.e. have a transmissivity, τ, that is zero).
- The target has an emissivity, ε, which we must know or be able to estimate with a reasonably high degree of accuracy.
- The target has a reflectivity, ρ, which the instrument can calculate.
- The target will receive radiation from the “surroundings”, and reflect this towards the instrument.

The influence of the atmosphere is a separate issue that will only be mentioned in passing in this paper. Emissivity is a factor that most thermographers are very familiar with, and that we know we cannot allow ourselves to ignore. With a non-transmissive target, the flip side of emissivity will be reflectivity. The instrument calculates this factor from the formula $\varepsilon + \rho = 1$ (emissivity plus reflectivity equals one). That is one reason (the more obvious one) that the target must be opaque. If it were not, the calculation of ρ would be impossible without further inputs. The complete measurement algorithm would become a nightmare. So let’s stay with opaque targets!

Another important conclusion to make from that is this: If you make a mistake on emissivity, you will make a mistake on reflectivity too. You will make two mistakes in one!

It is the influence from the last factor, the reflections from the surroundings that we will focus on here.

What is emission?

If you look it up you may find an explanation like: “an act of emitting” or “something set forth by emitting as electromagnetic waves by a celestial body”. What that means is that emission comes from the body itself. The target itself generates it.

The infrared radiation that is emitted by a target is depending on two things: the absolute temperature of the body, and the emissivity of the body.

The emissivity is a material property. It is the efficiency of the body as a radiator or emitter. The temperature is a result of the level of excitation that the atoms and molecules of the body have. The temperature is also what we want to know!

What is a reflection?

A dictionary might say that a reflection is “an instance of reflecting; especially: the return of light or sound waves from a surface” or “the production of an image by or as if by a mirror”. In our case, it is infrared radiation that bounces off our target. That radiation is part of the exitant radiation from the target, but it is not emitted by it! *The target itself does not generate it.*

The amount of reflected radiation that is exitant from a surface depends on two things: the reflectivity of the surface and the radiation incident upon it from somewhere else, and bounced off the target. This radiation leaves the target object completely unaffected.

The reflectivity is a material property of the target object itself. It is the efficiency of the target as a reflector. The incident radiation from the surroundings comes from…well, where does it come from? We will call this component “reflected apparent temperature”, or T_{refl}.

Total exitant radiation

From an opaque target, we will have two components of radiation exiting from the surface as shown in Figure 1: emitted and reflected. The first is generated by the target and is very valuable to us, because it is related to the temperature of our target. The second creates difficulties for us because it has nothing to do with the temperature of our target, but the camera “sees” it as coming from the target.

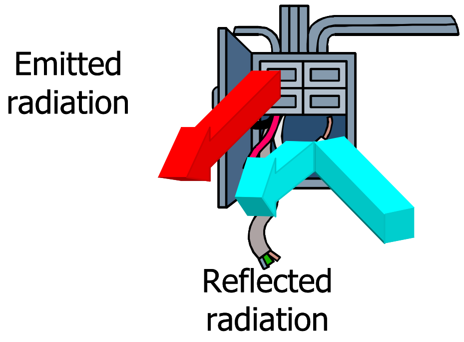

Figure 1. Exitant radiation from an opaque target

Everything is always reflecting something! Unless, of course, we are looking at a blackbody, which we are not.

Our conclusion must be that target temperature relates to emissivity the same way as “reflected apparent temperature” relates to reflectivity. It is just two sides of the same coin!

2. WHAT IS THE SOURCE OF THE REFLECTION?

What is "ambient"?

One of the most common misunderstandings about reflected apparent temperature is that it is the same thing as air temperature. It is not!!! The word "ambient" certainly suggests that it is, so the confusion is understandable. But let's look back at the second measurement condition above: The target must be located in a highly transmissive atmosphere. The wavelength band of the camera is specifically chosen so that the air has the highest possible transmissivity. That is why we have long wave (LW) and short wave (SW). The bit in between the two has a low transmissivity. In the band between LW and SW, the atmosphere will absorb radiation and emit radiation, none of which are desirable to us. But in the chosen wave band, the atmosphere is "invisible"!

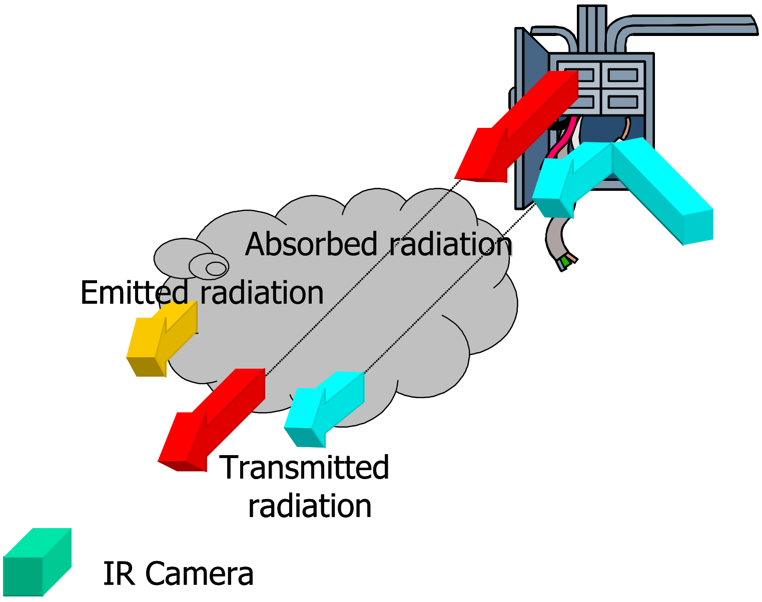

Figure 2: Radiation incident on the IR camera

Most of the radiation passes through the air; only a small portion of it is absorbed. The air emits a small amount of radiation. If the air had a high emissivity, it would be like looking through fog, our target would hardly be recognizable. All this is taken care of by the calculations that the camera makes, using the distance number we put in, and a few other factors.

The bottom line is: The atmosphere does not radiate much at all, so how could it be a significant part of "reflected apparent temperature"?

Further on, I will assume that the atmosphere is taken care of in the calculations that the camera makes, using our inputs for distance etc, and it is no longer a problem. At least not one I will discuss any more here.

What is "apparent temperature"?

Here is the definition of apparent temperature:

> **"Apparent temperature is the uncompensated reading from an IR instrument, containing all radiation incident on the instrument, regardless of its source."**

In Figure 2, the three radiation components that enter the camera after passing through, or being emitted by the atmosphere would represent "apparent temperature". Hold on a minute, "radiation components"? Yes, radiation! Apparent temperature is not a temperature at all, it is a radiation quantity! Our definition says that it is an "uncompensated reading". Only after the compensation will we read true temperature. And all the camera sees is infrared radiation, not temperature. The camera has no way of knowing where a particular part of the radiation that enters its front lens is coming from. It just adds it all up and presents an image of it, an image that represents variations in radiation intensity from various directions in the field of view.

What is "reflected apparent temperature"?

Apparent temperature is the radiation incident on the camera. In much the same way, reflected apparent temperature is incident on the target object, and then reflected into the camera, thus becoming a part of the apparent temperature the camera sees.

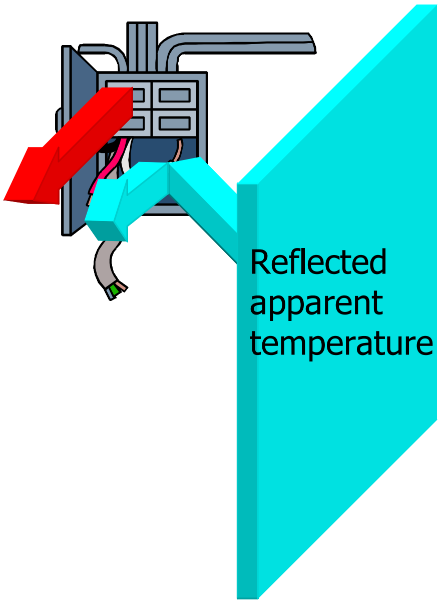

Figure 3: The source of the reflected radiation is called reflected apparent temperature

For a concise definition we could use something like this:

"Reflected apparent temperature is the apparent temperature of whatever object it is that is reflected off the target into the camera."

This definition puts forth a number of conditions for reflected apparent temperature.

It is not a true temperature: If the true temperature of the reflection source is a certain number, and the emissivity is less than 1.0, which it will be, the radiation from the source will correspond to a lower apparent temperature. Some radiation that the source "should" radiate is never emitted from the surface. And if it is never emitted, it cannot be reflected either.

It comes from an object or objects: A solid object will radiate a lot more than air will ever do. The air will give a contribution, but it is infinitely small. An exception, however notable, is the sky. The sky is not a normal "object", but it doesn't matter, because it can be treated just as if it were. The main point is: reflected apparent temperature is not the temperature of the air around the camera or the target.

It must actually be reflected into the IR camera: The reflection source must have a suitable angle of incidence on the target, to become a part of the exitant radiation towards the camera. This depends on the reflection characteristics of the target. Some targets will give a reflection that looks like "an image by or as if by a mirror". Those are called specular reflectors. Other targets will scatter the radiation in all directions. We call those diffuse reflectors.

The difference between types of reflectors will be discussed further below.

How can we compensate for reflected apparent temperature?

In Figure 3, the left arrow represents the emitted radiation from the target itself. This radiation can be calculated as:

$$W_E = \varepsilon * \sigma * T^4$$

This is according to the Stefan-Boltzmann Law. If we know the radiation, the emissivity, and the Stefan-Boltzmann constant □, we can calculate the temperature. That's simplified, but absolutely true in principle.

It is the right arrow, the reflected bit that creates the problems that we must sort out first. It is unwanted radiation that enters the camera. Using the principles described in the paragraph just above, the amount of that radiation must be calculated, so it can be removed from the further calculations of true temperature.

How can the reflected component be calculated? We said before that it depends on two things: the reflectivity of the surface and the apparent temperature of the radiation incident upon it from somewhere else, and bounced off the target into the IR camera. If we know the reflectivity and the reflected apparent temperature, this calculation can be made:

$$W_{refl} = \rho * \sigma * T^4_{refl}$$

When W_{refl} is calculated, it can be removed from the grand total that the camera sees, and the rest is just the emitted radiation from the target. That radiation is converted to temperature, using the calibration curve in the camera (1).

3. WHERE DO MY REFLECTIONS COME FROM? HOW BIG IS "RAT"?

We must estimate and input T_{refl} in the camera. The difficulty of finding out T_{refl} will vary with a number of different factors.

1. Spot reflection sources vs. large, even reflectors

Let's define two types of reflectors in principle; spot sources and hemi-spherical sources (for lack of a better word). Most measurement situations will include components of both these two ideal cases.

The spot source would be a small hot or cold surface with significant difference from its surrounding apparent temperature. It would have a small spatial angle towards the target. Examples could be the sun, light bulbs, heaters, air conditioning vents, etc.

The hemi-spherical source would be large, and have an even apparent temperature all over. Imagine a basketball cut in half and placed over the target. The apparent temperature radiating from the inside of the half-sphere would be the source of reflection. Examples could be inside a room with uniform temperature walls, a case when the sky has a uniform even temperature (clear, or a uniform cloud-cover).

2. The easy case

You are inside a room where the temperature of all the walls is the same, and the same as air temperature. Your hot or cold target is the only thing that deviates from this temperature. You have a clear case of a hemi-spherical reflection source.

In such a situation, you are virtually inside a blackbody. The apparent temperature of the walls will be the same as their true temperature. Whatever you set for object parameters in the camera, you will read true temperature. (Well, in theory at least. Imperfections in the algorithms can cause some errors if you set extreme values.)

In practice, what you will do is to put your emissivity at 1.0, and your distance to 0. That means that you will not do any compensation at all. The camera will display apparent temperature. Your settings for T_{refl} and humidity, etc. can be ignored. If emissivity is 1.0, reflectivity is zero; no reflected quantity will be calculated. If distance is zero, we assume that there is no air between the camera and the target.

In this case, it makes no difference how the surface reacts to incoming radiation directionally, because the apparent temperature will be the same from all directions.

3. Specular and diffuse reflectors – a little more difficult

These two characteristic traits are a bit the same as blackbodies – they don't exist in real life. But they are useful ideal surfaces for the sake of discussion, and they can be exactly defined.

Specular: An incoming beam of radiation will have the same angle going in as going out, like this:

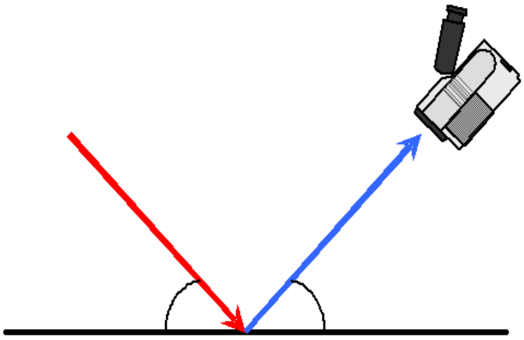

Figure 4: Specular reflection has the same angle going in as going out

The surface will act as a mirror. We can therefore define exactly what our reflection source is. Any heat source that is not within the spatial angle of the mirror like reflection will not be part of reflected apparent temperature at all!

Conclusion: If this is the type of reflector you are dealing with, all you have to worry about is move around until all spot sources are outside of your reflection direction.

Diffuse: A diffuse reflector will reflect any incoming radiation equally in all directions. A spot reflection will be spread out and diluted. That means that a very small proportion of the spot reflection will be going in the direction of your camera. (Please note that this picture is only two-dimensional, whereas the phenomena itself is three-dimensional – a half-sphere.) It would look like this:

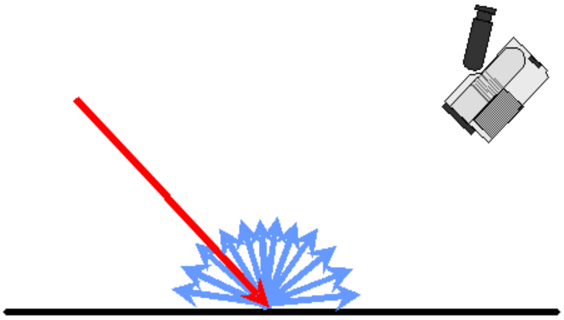

Figure 5: Diffuse reflections are equal in all directions

Conclusion: A diffuse reflector will always reflect an average of what is incident upon it from the half-sphere it is facing.

4. What will your surface be? Specular or diffuse?

This is a tough one. It is just as tough as making a generally useful emissivity table. And we all know that tables can fool you badly.

But there are a few things that can be said that are generally valid.

Your target will be more specular than you think: If your target is a flat piece of metal that looks like it is fairly low emissivity, it will be more specular in infrared than in visual. That is because infrared cameras are sensitive to longer wavelengths than our eyes. You can try this very easily. Take a piece of non-polished, flat metal. Look at it and see if you can see yourself like in a mirror. You can't? OK. Now put it in a 45-degree angle in front of your IR lens and aim that "periscope" at something. What do you see? Very likely a pretty good picture! That will mean that you are more probable to have a situation as in Figure 4, on low emissivity targets.

A spot source will not be very significant on a diffuse target: If your target is a diffuse reflector it will very likely have a high emissivity and a low reflectivity. That means that reflections in general will not have a very high influence. Another reason is that your spot reflection source will be highly diluted before it reaches your camera – it will be a small part of the average of your hemi-sphere. Compared to the whole half-sphere, the size of your spot source could almost be ignored.

Measuring reflected apparent temperature

I said before that T_{refl} or T-ambient is not the same as the air temperature. Well, funny enough, sometimes air temperature is the same as T_{refl}! How does that work? The reason is that some cameras have saved on the user inputs, and because air temperature is a lot less significant in the calculation, it is set to be equal to T_{refl}, whether that is the correct number or not (it is never the same thing!). When you measure T_{refl}, don't let that influence you at all. Measure T_{refl} correctly, and ignore air temperature, if it has no separate input.

Because T_{refl} is an apparent temperature, the camera should be set at 1.0 emissivity and 0 distance. That will give us the uncompensated reading that we need. With those settings, it doesn't matter what you set T_{refl} to, because your reflectivity setting is zero (since emissivity is 1.0). So the camera will calculate no reflected radiation. It thinks it is looking at a blackbody. In fact, it thinks it is inside it, because distance is 0. That means it makes no difference what air temperature or relative humidity is set to either.

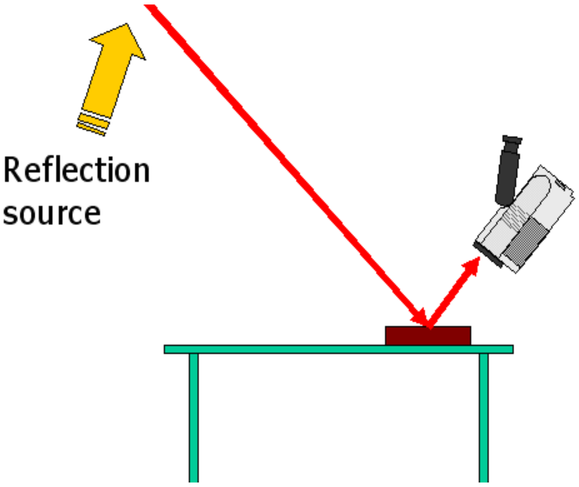

Figure 6: Finding the source of reflection

The next thing to do is determine the source of reflection. Look around you, and look at the target. Do you have spot reflection sources around? Does your target object show obvious reflections from spot sources? If it does, try to determine where the sources are, and move the camera to avoid them. Your target will now be reflecting whatever is next to your spot sources, and that is where your T_{refl} will come from. Aim the camera at it and measure its apparent temperature. Put in the number you get as T_{refl}, set emissivity and the rest, and measure your target temperature.

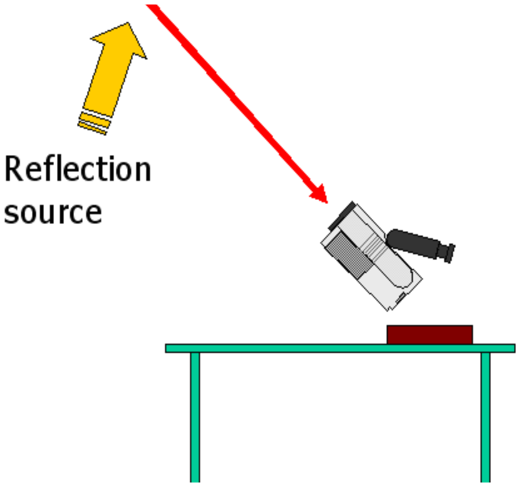

Figure 7: Measuring reflected apparent temperature

If there are no suspected spot reflection sources, use the angle-in = angle-out rule, and try to find out what surface will be reflecting. Take your T_{ref}l from that surface.

Another solution to spot sources reflecting is to shield them off. You can use any high emissivity material, like a piece of cardboard, for example. Measure its apparent temperature and make sure handle it in such a way that it stays that temperature. Another tip, if you work in electrical cabinets, is to use the cabinet door. Close it slightly, and look into a smaller opening. The door may shield off unwanted sources. (But make sure it doesn't have hot sources on it, like lamps, etc.!)

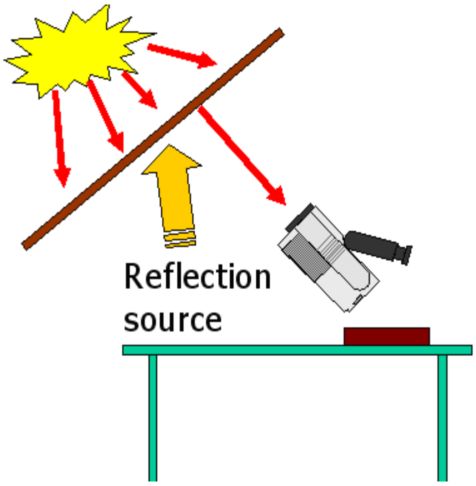

Figure 8: Shielding off unwanted radiation

If your target surface is diffuse, and you have spot reflection sources, the question is: do they influence your measurement? You can try to find out by changing angles, shielding off the sources, etc. If you find no real change in temperature, you can ignore the spot sources. If that is not the case, you need a measurement of T_{refl} that takes the spot sources into account. The ideal solution would be to take a weighted average of the apparent temperature your target is seeing, from the whole hemi-sphere. There could be practical difficulties in doing that. A frequently suggested method is to use a piece of aluminium foil that is first crinkled up and then pulled back out, so that we get a diffuse reflector with a high reflectivity. It is then put in front of the target and the reflected apparent temperature is measured as an average from its reflection. I suggest you stay with emissivity 1.0, although the reflectivity of the foil is not 100%. Using a lower number for emissivity to compensate for the absorption will bring in T_{refl} into the calculation again, which will complicate it.

A very peculiar input mode exists on some cameras. There is no numerical and direct input of the value. It is entered by putting the lens cap over the lens and performing a measurement on the lens cap with a specific routine. The camera then uses that radiation level as the reflected apparent temperature in the calculations. This obviously limits the flexibility of the system a great deal. In practice, it will always be assumed that RAT and air temperature is the same. If you own such a camera; whatever you do, don't pick the lens cap from your pocket when you do the T_{refl} measurement! Make sure it is at ambient air temperature, and preferably stay indoors in a controlled environment when you do your measurements.

4. POTENTIAL ERRORS FROM IGNORING "RAT"

The funny thing is that after all my effort explaining all that stuff above, making sure that it is understood that reflected apparent temperature is not the same thing as air temperature, it usually boils down to being the same number anyway! The same number – not the same thing… Most of the time, we have a case very much like the "easy case" above, where T_{refl} will be equal to air temperature. That's because temperatures tend to equalize in a room. This is probably why so many people have been able to get fairly good results, in spite of the misunderstandings that have existed.

However, we are not always that lucky.

1. Playing "what if?"

Playing "what if?" is a very useful exercise if you want to find out just how far off your measurement could be in any given situation. "What if I change the emissivity from value x to value y? What will I be reading then?"

Here are a few fictitious cases. The camera I will be "picking the brains" of is a FLIR Systems PM 695, a long wave camera. We assume that we are measuring a target with a true temperature of 80°C, and the true T_{refl} (or T_{amb} , as it is called in this camera) is 20°C. Distance is set to nil, to eliminate the influence of air temperature and relative humidity.

Example 1: Emissivity is 0.8

T_{refl} , or T_{amb}	Camera calculated value	Measurement error
-20°C	84.9°C	+4.9 K
0°C	82.7°C	+2.7 K
20°C	80°C	0 K
40°C	76.5°C	-3.5 K
60°C	72.3°C	-7.7 K

Example 2: Emissivity is 0.5

T_{refl} , or T_{amb}	Camera calculated value	Measurement error
-20°C	98.7°C	+18.7 K
0°C	90.8°C	+10.8 K
20°C	80°C	0 K
40°C	65.6°C	-14.4 K
60°C	46.6°C	-33.4 K

Example 3: Emissivity is 0.2

T_{refl} , or T_{amb}	Camera calculated value	Measurement error
-20°C	147°C	+67 K
0°C	120°C	+40 K
20°C	80°C	0 K
40°C	9.8°C	-70.2 K
60°C	< - 273°C	>353 K

Wow! By making a little mistake, I have been able to reach what scientists have tried for ages. I have gone below absolute zero!!! Wonder what I will do with the Nobel Prize Money…

What happens there is that the instrument goes beyond the calibrated range. Simply put, it goes bananas. I do too when I have to measure temperature of targets with an emissivity that low.

Already at an emissivity of 0.5, we can see that it starts to get really sensitive. Not the same “monster RAT” as 0.2, but the errors are very significant.

At an emissivity of 0.8, the errors are perhaps acceptable as long as we are within +/- 20 K of the correct value for T_{refl} . In a lot of cases, we might even live with the errors that a mistake of +/- 40 K will produce. It depends on the application and the criticality of the decision we have to make based on the measurement.

2. Playing with fire

One of the more extreme applications that people do is measuring inside furnaces. Using a short wave camera with a properly matched filter for the application makes it not so different from other applications, if the flames are burning reasonably clean. Heavy fuels can make the atmosphere full of particles that create a lot of absorption, but that whole discussion is outside of the subject for this paper.

Let us assume that we are looking into a furnace that is cylindrical, and standing up. The furnace tubes are standing up too, and located in a circle just inside the furnace wall. Looking in through an inspection port – at the tubes across the furnace, it might look like this:

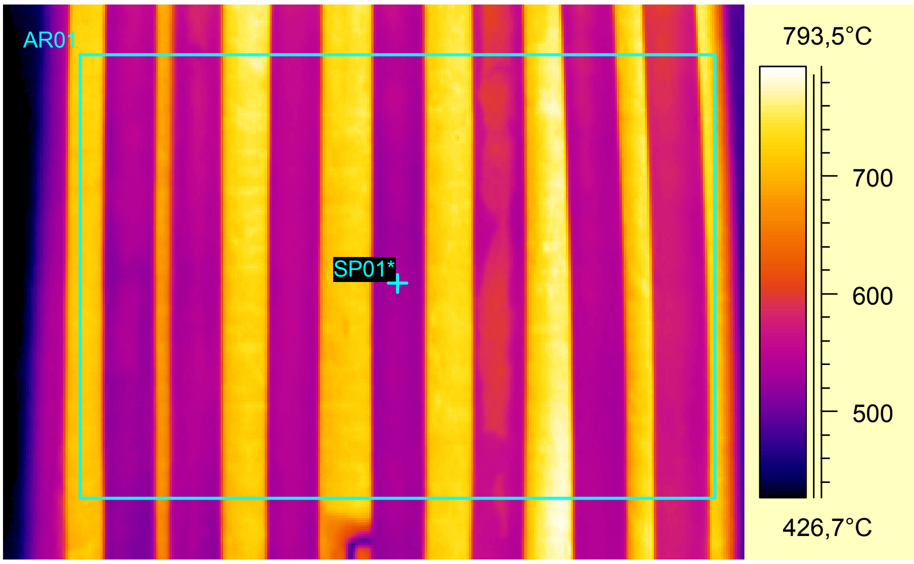

Figure 9: Thermogram of furnace tubes

What should be our T_{refl} ? My estimate is that we can assume the tubes to be diffuse targets. The surface is rough, and the material is basically rust. On top of that, it is a rounded surface. So if we want to look from here, and measure on these tubes, we should probably get the T_{refl} from the inspection port that we can see a part of at the bottom of the image, in the middle. That is, if we went to the other side and looked back this way, we would use this as T_{refl}. And when we are there, we should take an image using an emissivity of 1.0 and a distance of 0. For simplicity, let us assume that the image we take from there is identical to this one. This image is in fact set at emissivity 1.0 and distance 0. Inside the area, the average temperature is about 624°C. That is then our Trefl !

Using that number for T_{refl}, we get a temperature from the spot in this image of 520°C. Emissivity is assumed to be 0.90. (The spot has different settings that the rest of the image.)

If we would make the cardinal mistake of not considering T_{refl} and leave it where it was (say, 20°C) when we left the electrical room earlier, we would measure 550°C, at an emissivity of 0.90. An error of 30 K doesn't sound like a lot, but that is because of the high emissivity.

Having obtained a reasonably correct measurement, it is another story how it would be used. There are plenty of knowledgeable petroleum engineers in this world, and I am not one of them. I therefore leave the rest of the subject open. I also leave it to others to estimate how serious our assumed measurement error of 30 K is.

And by the way, if you forget to return to "normal" value for T_{refl} when you leave the furnace, your camera might go bananas again! Even a target with a 0.90 emissivity will reflect a huge amount of radiation from 600°C, so the camera may go outside of the calibrated region, just like it did in Example 3 above. If that happens, don't embarrass yourself by sending your camera in for service!

5. A SIDE NOTE: CAN I MEASURE EMISSIVITY WITH A REFLECTION METHOD?

This paper is about reflected apparent temperature, but I cannot resist the temptation of discussing something that is intimately related to the discussion above.

If we are looking at an opaque surface, a bus bar for example, and we need to know the emissivity, it would seem that if we were able to measure the reflectivity, we would also know the emissivity. Yep, that's true! It is not so straightforward to measure the reflectivity though. Here is a suggested method that has been around for a whole lot of years, and has probably puzzled more people than me, because it seems that it should work.

To measure reflectivity, you need a stable radiator with a high emissivity and a known apparent temperature. It can be measured just by looking at it with the camera, and setting emissivity to 1.0 and distance to 0. The apparent temperature of the source is noted. Next step is to place the camera and the radiation source so that a reflection can be seen in the camera. It is crucial at this step that the camera is focused on the reflection source, not the target! Then measure the temperature of the source, lowering the emissivity setting until the previously noted apparent temperature is reached. The emissivity number in your camera is now your reflectivity, because it is based on what is left after some radiation has been absorbed.

For this to work your target must be a perfectly flat specular reflector, otherwise there will be an amount of radiation lost to scattering at the surface, in addition to the expected loss to absorption. (Which is also why focusing on the reflection source is important.) Using this method, you will always measure an emissivity that is too high. On a hot target, that would result in a temperature measurement later that is too low. But hey, is that so bad? If we are in trouble with low emissivity, we may be grasping at whatever chance we have to get more information, and at least get closer to a true reading. If we can say: “It is hotter than this”, that may be a step ahead.

But the answer to the question above must be: No. You cannot measure emissivity with reflections in most cases.

6. SUMMARY

You cannot afford to ignore the RAT! And as usual, infrared temperature measurement gets worse the lower the emissivity is. That’s no surprise, is it! The key word to handling RAT is CONTROL. You must control what is reflecting off your target into your IR camera. That means that you must keep spot reflections out of your target, and know what is reflecting from your target, and what its apparent temperature is. The absolute minimum is that you know what your reflected apparent temperature is set at, so that you are able to estimate whether that is reasonable or not.

Playing “what if?” with your camera is a great way to find out where you are standing as far as expected measurement accuracy goes. This is valid in many other situations, not only for reflected apparent temperature.

Two things prompted me to write this paper. Firstly: Having trained many people in infrared thermography over the years, some having way over twenty years of daily thermography experience, but little formal training, I have seen plenty of proof that this is probably the most widely misunderstood measurement parameter today. Secondly: It seemed timely to take the opportunity at a time when we are changing the terminology to something we hope will be easier to intuitively understand. At least harder to misunderstand!

7. REFERENCES

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