FLIR

TECHNICAL NOTE

Seeing through fog and rain with a thermal imaging camera

Metrological effects of Fog & Rain upon IR Camera Performance

The PTZ-35x140 MS is a thermal imaging system incorporating two thermal imaging cameras and a daylight/lowlight camera. Both thermal imaging cameras are equipped with a longwave uncooled microbolometer detector, offering excellent range performance in fog.

Thermal imaging cameras can produce a clear image in total darkness. They need no light at all to produce a crisp image in which the smallest of details can be seen. It makes them an excellent instrument for numerous night vision applications.

"How far can you see with a thermal imaging camera?" is a frequently asked question which is extremely important to answer for most night vision applications. The distance you can see with a thermal imaging camera, also called the range, is highly dependant on a number of camera variables: What lens are you using? Is the camera equipped with a cooled or uncooled detector? What is the sensitivity? What is the size of the object you want to detect? What is the temperature of the target and the background?

The "How Far..."question is most often answered under ideal climatological conditions so the next question that needs to be answered is then : "What happens to the range in fog, rain or other climatic conditions?"

Although thermal imaging cameras can see in total darkness, through light fog, light rain and snow, the distance they can see is affected by these atmospheric conditions.

Transmittance of infrared radiation

Even in clear skies, inherent atmospheric absorption places limits on how far a particular infrared camera can see. A thermal imaging camera produces an image based on the differences in thermal radiation that an object emits. In essence, the farther this infrared signal has to travel from the target to the camera, the more of that signal can be lost along the way.

As such, the attenuation factor needs to be taken into account. This is the ratio of the incident radiation to the radiation transmitted through a shielding material. Humid air acts as a "shield" for infrared radiation. Summer month atmospheres usually have a higher attenuation compared to winter months due to increased humidity levels. Therefore, assuming clear skies and good weather conditions, you will be able to see farther with a thermal imaging camera in winter than in summer.

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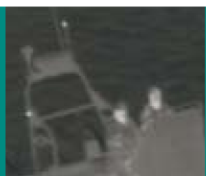
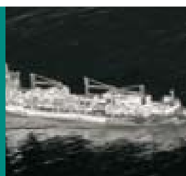


HRC-Multisensor

ThermoVision 3000 Multisensor

The HRC and the ThermoVision 3000 Multisensor are both equipped with a cooled detector. The HRC is equipped with a Indium Antimonide (InSb) detector operating in the 3 – 5 µm midwave IR band. The ThermoVision 3000 incorporates a Quantum Well Infrared Photodetector operating in the 8 – 9 µm longwave IR band. Both can detect man sized targets at extremely long ranges.

But humid air is just one example of how infrared radiation can be lost. There are other climatic conditions which are far more detrimental to the range of a thermal imaging camera.

Fog and rain can severely limit the range of a thermal imaging system due to scattering of light off droplets of water. The higher the density of droplets, the more the infrared signal is diminished. An important question that customers ask is how much rain or fog will limit the range performance of a thermal infrared camera, and how does this compare to the range in the visible region of the spectrum.

Fog classifications

Fog is a visible aggregate of minute water droplets suspended in the atmosphere at or near the surface of the earth. When air is almost saturated with water vapor, this means that the relative humidity is close to 100%, and that fog can form in the presence of a sufficient number of condensation nuclei, which can be smoke or dust particles.

There are different types of fog. Advection fog is formed through the mixing of two air masses with different temperatures and/or humidity. Another form is radiative fog. This is formed in a process of radiative cooling of the air at temperatures close to the dew point.

Some fogbanks are denser than others because the water droplets have grown bigger through accretion. In fog conditions droplets can absorb more water and grow considerably in size. The question whether scattering is less in the IR waveband compared to the visible range depends on the size distribution of the droplets.

There are different ways to classify fog. An often-used classification is the one used by the International Civil Aviation Organization (ICAO). According to this system, fog can be classified in 4 categories:

Category I: visual range 1220 meters
Category II: visual range 610 meters
Category IIIa: visual range 305 meters
Category IIIc: visual range 92 meters

The reason for degradation of visibility in a foggy atmosphere is the absorption and scattering of natural or artificial illumination by fog particles. The amount of absorption and scattering depends on the microphysical structure of the fog particles, which are also called aerosols.

Moderate Resolution Propagation Model (MODTRAN)

MODTRAN is an atmospheric radiative transfer code created and supported by the United States Air Force. It has the ability to model the atmosphere under a variety of atmospheric conditions. It can predict atmospheric properties including path radiances, path transmission, sky radiances and surface reaching solar and lunar irradiances for a wide range of wavelengths and spectral resolutions.

MODTRAN enables the calculation of transmittance and radiance in a wide spectral range. It offers six climate models for different geographical latitudes and seasons. The model also defines six different aerosol types which can appear in each of the climates. Each of the climate models can be combined with the different aerosols.

How far you can see through fog or rain with a thermal imaging camera will also depend on the climate in which you are using the camera and the type of aerosol which is present in this specific climate.

Climate	Aerosol
Tropical	Rural
Midlatitude summer	Maritime
Midlatitude winter	Urban
Subarctic summer	Advection fog
Subarctic winter	Radiative fog
US Standard	Desert

The input data for the MODTRAN model

The input data for the MODTRAN model are the above mentioned specific climates and aerosols but also the visibility according to ICAO categories, geometry and length of the atmospheric path and the temperature and emissivity of target and background.

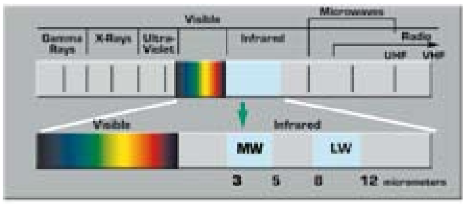
In general, a comparison of the different aerosols shows that the maritime aerosols always result in the lowest detection range independent of the climate model, since maritime aerosols have in average greater particle radii than rural and urban aerosols. The rural and urban aerosols produce noticeably greater detection ranges in the infrared band.

This means that you can see less well through fog in maritime conditions than in land conditions, irrespective of the climate type.

Thermal imaging camera and target

Just as the type and thickness of the atmosphere has an influence on how far one can see through fog, the type of infrared camera used and specifically the waveband in which the camera operates are also of importance.

There are two wavebands of importance for thermal imaging cameras: 3.0-5µm (MWIR) and 8-12µm (LWIR). The 5-8µm band is blocked by spectral absorption of the atmosphere by water vapor to such a tremendous extent that it is rarely used for imaging.



The electromagnetic spectrum

Thermal imaging cameras that are equipped with uncooled sensors are designed to work in the longwave infrared (LWIR) band between 7 and 14 microns in wavelength, where terrestrial targets emit most of their infrared energy and uncooled detection is easy.

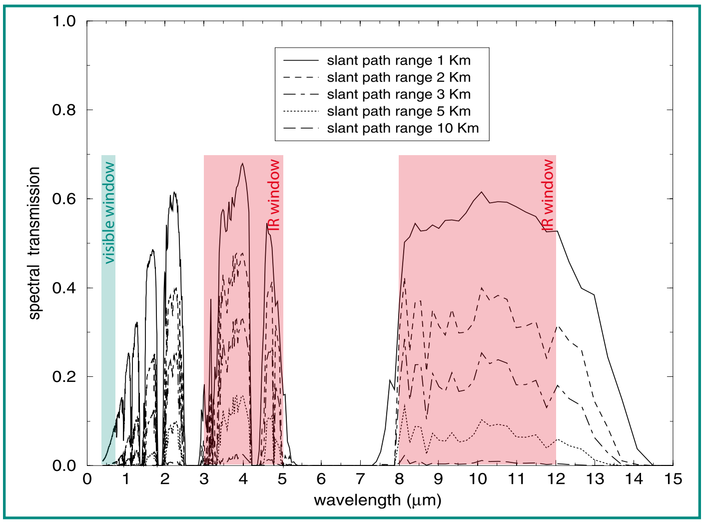
Thermal cameras that are equipped with cooled detectors (where the sensors are cooled to cryogenic temperatures) are the most sensitive to small temperature differences in scene temperature and are generally designed to image in the midwave infrared band (MWIR) or in the longwave (LWIR) band.

The spectral transmission is different in the MWIR and the LWIR bands. Therefore there will be a difference how far one can see through fog with a thermal imaging camera equipped with an uncooled LWIR detector compared to a cooled MWIR detector.

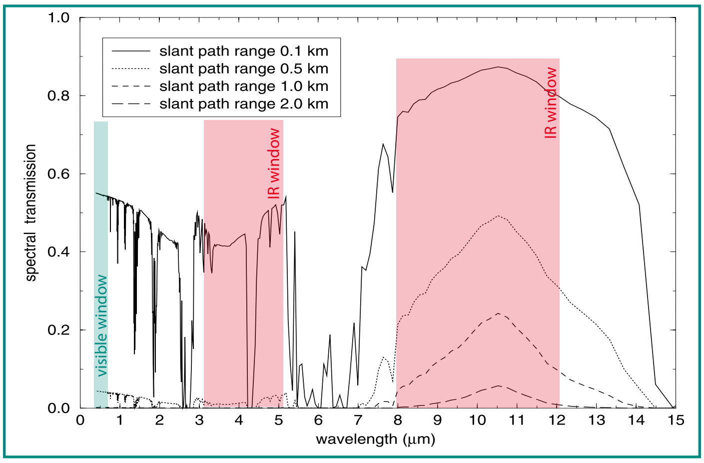
Atmospheric Transmission Model Results - Fog

The spectral transmission of the atmosphere for varying ranges enables a simple qualitative comparison of the visibility in different atmospheric windows.

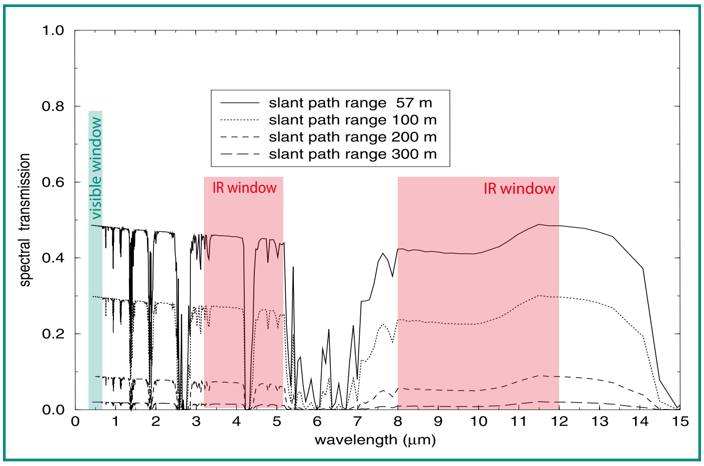
Figure 1 shows the spectral transmission for CAT I fog in midlatitude summer and rural aerosols. In the visible spectral waveband (0.4 - 0.75 microns) the transmission is significantly lower than in both thermal IR windows (between 3-5 and 8-12 microns). In these conditions a thermal imaging camera will see significantly further than the naked eye regardless whether it is using a longwave or midwave detector.



When we reduce the visibility to CAT II conditions with radiative fog in the model, then it predicts that only the LWIR (8-12 microns) band is superior to the visible band, and that a midwave infrared camera will not see much further than the naked eye. (Figure 2)



Finally, in Cat III conditions (Figure 3), with visibility less than 300 m, there are no substantial differences between how far you can see with a thermal imaging camera and how far you can see with the naked eye.



The transmission alone does not fully determine how far and what you can see, but the comparison between visual and IR transmission shows whether the atmosphere favors or discriminates a certain waveband.

Detection range

The conditions of the atmosphere alone aren't enough to predict how far one can see through fog or rain. The size of the target and the temperature difference with the background both need to be taken into account. Furthermore, the limited spatial resolution of the optics and the detector, and the noise of the detector and signal processing also reduce the contrast radiance of target to background. The influence of the infrared sensor's transfer functions on the contrast radiance is simulated with the TACOM Thermal Image Model (TTIM). This model enables to simulate different types of IR sensors with focal plane arrays.

The table below compares the detection range in kilometers through fog with the naked eye, a MWIR camera and an LWIR camera, given a temperature difference of 10°C between the target and the background and a detection threshold of 0.15 K

Fog Category	Visual	MWIR	LWIR
Cat I	1.22	3.0 – 9.8	5.9 – 10.1
Cat II	0.61	0.54	2.4
Cat IIIa	0.305	0.294	0.293
Cat III c	0.092	0.089	0.087

For Cat I, the IR detection range is given in a range span, representing the variation within different climates and aerosols as specified in MODTRAN. In the LWIR the best conditions occur in winter with low absolute humidity and a rural aerosol distribution. In the MWIR band the detection range is best in conditions with high temperatures , like a summer or tropical atmosphere.

All detection ranges for IR are significantly better than the visual for Cat I type of fog. For Cat II type of fog the result is four times better with a thermal imaging camera equipped with a LWIR detector compared to visual.

In Cat IIIa and Cat IIIc types of fog, there is virtually no difference between how far you can see with a thermal imaging camera and with the naked eye since the atmosphere is the limiting factor. Radiation does not penetrate through this dense type of fog in all (visible, MWIR and LWIR) spectral bands.

Conclusion & results

According to these models, Cat I and Cat II types of fog, the thermal IR band offers better range performance compared to the visual band. As such, thermal IR cameras are well suited to look through these types of fog. The models suggest that thermal imaging cameras are potentially useful as landing aids for airplanes or as part of driver vision enhancement systems for the transportation and automotive industry.

The models suggest that fog penetration is higher in the LWIR compared to the MWIR band in all studied cases. For Cat II type of fog, the LWIR spectral band offers about four times better range performance compared to the MWIR band. However, sensor thermal sensitivity and the target signatures must be taken into account to arrive at a final selection of the best system to meet the application. Also cost considerations come into play. For instance, for security & surveillance applications, it is generally not economical to use uncooled LWIR systems for longer ranges as the lenses become too big and expensive.

MWIR radiation is adversely affected by atmospheric pollutants and pollutant gases (possible increased atmospheric absorption and/or increase levels of in-path radiance – both of which reduce target image contrast). LWIR is much less affected.

Rain can significantly reduce target contrast (due to increased atmospheric scattering and general obscuration) and LWIR and MWIR perform similarly in the presence of rain. IR system performance degradation due to rain is very range sensitive, whereby there is a dramatic drop off in the 100-500 meter range.

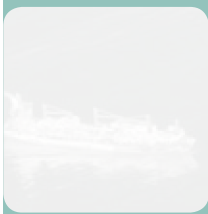
Just like it is impossible to give a simple answer to the question "How far can I see with a thermal imaging camera?", it is equally impossible to say how much shorter the range will be in foggy or rainy conditions. This is not only dependant on the atmospheric conditions and the type of fog but it is also dependent on the IR camera used and on the properties of the target (size, temperature difference of the target and background, etc)

Fog

Thermal image

Fog

Thermal image



Fog

Thermal image

Fog

Thermal image

Being able to see through fog is useful for a lot of applications. Maritime, security, automotive and aviation applications can all benefit from the power of thermal imaging and its ability to see further through most types of fog than the naked eye or a CCTV camera

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References:

K. Beier, H. Gemperlein, Simulation of infrared detection range at fog conditions for Enhanced Vision Systems in civil aviation in Aerospace Science and Technology 8 (2004) 63 - 71

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