FLIR

TECHNICAL NOTE

Thermal imaging:
how far can you see with it?

A FLIR PT-Series thermal imaging camera

Often, the first question that people interested in buying a thermal imaging camera ask is "How far can I see?" This is a very reasonable question to ask, but it defies any simple answer. All FLIR Systems thermal imaging cameras are able to see the sun which is more than 146 million kilometers away from Earth. But it would be totally wrong to say that all FLIR Systems thermal imaging cameras can detect security threats at this distance.

Thermal imaging is a technology that enables detection of people and objects in total darkness and in very diverse weather conditions. A typical application for thermal imaging is border security, where most threats occur at night. Watchtowers spaced at 4km intervals or more have to be able to detect threats at ranges up to 2km or more to guarantee full coverage of the border. Knowing how far you can see with a thermal imaging camera and at which distance you can detect a possible threat is of the utmost importance.

The distance you can see a given target with a thermal imaging camera is called the "range" in the thermal imaging industry. To correctly determine the range of a thermal imaging camera requires some sophisticated modeling. There are many variables to consider including the type of thermal imaging camera you are using, the type of lens you are using, the nature and size of the object you want to detect, the atmospheric conditions and the very definition of what it means to "see" a target.

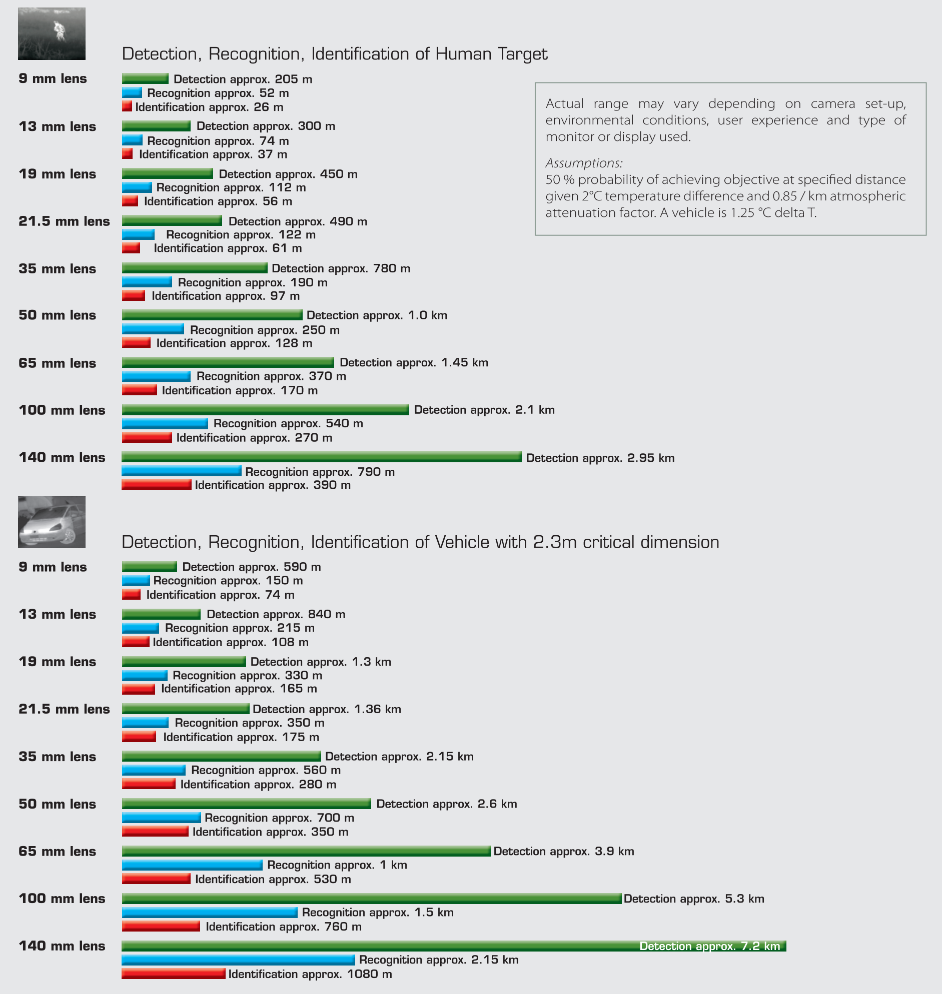
"Seeing" an object

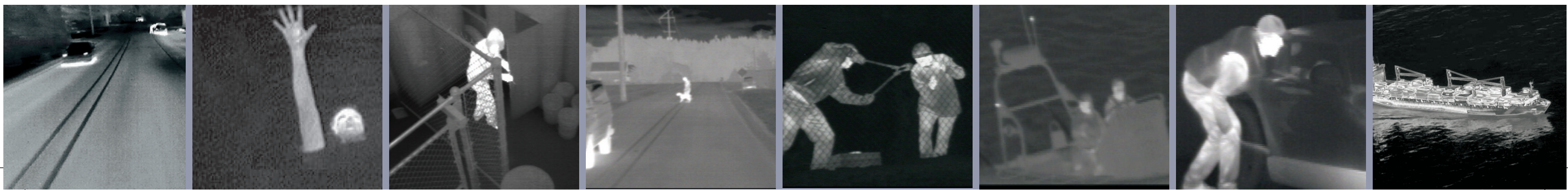
To define what is meant by "seeing a target", the so-called Johnson's criteria can be used. John Johnson, a Night Vision & Electronic Sensors Directorate scientist, developed criteria that relate to the effective range of infrared cameras. Although developed for the military (hence the use of the term "target" to refer to the object of interest), the Johnson criteria are widely used in the commercial marketplace to characterize thermal imaging systems. According to these criteria a distinction needs to be made between degrees of "seeing" a target:

- **Detection:** In order to detect if an object is present or not, its critical dimension needs to be covered by 1.5 or more pixels. 1.5 pixels in a staring array is equivalent to 0.75 "cycles", which is the unit of system resolution originally used in Johnson's definition.

- **Recognition:** Recognizing an object is defined as seeing what type of object it is. It means being able to make the distinction between a person, a car, a truck or any other object. In order to recognize an object it needs to be subtended by at least 6 pixels across its critical dimension.

Detection, Recognition, Identification using a Thermal Imaging camera with 25 micron pitch detector





- **Identification:** This term is often used in the military sense of the word, which means seeing if someone is "friend or foe". In order to do this, the critical dimension of the object in question needs to be subtended by at least 12 pixels.

These Johnson's criteria give a 50% probability of an observer discriminating an object to the specified level. For example, an adult human being is roughly 1.8m by 0.5m in size. The "critical dimension" of this man is 0.75m, according to empirical fits to the statistical analysis of observers and thermal image data. Consider an infrared camera system which has sufficient resolution such that 6 pixels in the image correspond to a target critical dimension of 0.75 meters at 1000 meters range. Furthermore, let us suppose that the camera sensor receives sufficient thermal contrast between the target and the background, i.e. a person against a cool nighttime landscape. Then the system has a reasonable probability of recognition at 1000m range.

FLIR Systems specifies how far you can see with a thermal imaging camera by specifying at which distance our thermal imaging systems can detect a man-sized target in conditions that yield sufficient thermal contrast. Depending on the lens size, our infrared camera systems can detect human activity up to several kilometers away. As the object that needs to be detected increases in size, the maximum detection range also increases.

Focal length: an important parameter:

A critical parameter that affects how far one can see with a thermal imaging camera is the focal length of the lens. The focal length determines the instantaneous field of view (IFoV) of a camera system. This is the angular field of view of a single pixel – the smallest angle that can be resolved by the system, provided that there is sufficient thermal contrast.

The IFoV then determines the distance at which a target's critical dimension subtends the required number of pixels to achieve detection, recognition or identification. The longer the focal length of the lens, the smaller the IFoV becomes, which translates into more pixels across a target at a fixed range. Long-range security applications such as border security require quite small IFoVs, because the imaging systems have to detect objects the size of a man at a distance of several kilometers away. It should also be noted that the total field of view scales inversely with focal length - long lenses give small fields of view. This is the compromise: long lenses on cameras trade longer range detection for reduced total field of view. In other words, you can identify targets, but you need to know where to look for them in the scene, since the system is essentially looking through a soda straw! As a result, infrared camera systems often have multiple focal length lenses to enable rapid target detection with subsequent identification when the system zooms in.

Consider a man at a range of 1km. The effective angle that he subtends is the critical dimension divided by the range, which is 0.75m/1000m or 750 microradians in angle. In order to properly identify the man at this range with a thermal imaging camera, we need a system that gives us 12 pixels across 0.75 meters at 1000m. Note that in this context identification does not mean identifying a particular individual, but rather making the distinction between a man holding a rifle from a man holding a shovel, for example. A 500mm focal length lens combined with a camera sensor with 15 micron pixels gives an IFoV of 30 microradians. The number of pixels on target is equal to the target angle divided by the IFoV angle. Therefore, we will have 750 microradians divided by 30 microradians per pixel, or approximately 25 pixels on target – exceeding the 12 pixel requirement for identification.

Cooled versus uncooled thermal imaging cameras

There is also a difference between how far you can see with a cooled and with an uncooled thermal imaging camera. Cooled camera systems are more expensive, but generally have a longer range than uncooled systems under many conditions.

A typical cooled camera has a 15 micron pixel pitch (spacing between pixel centers). A 500mm lens on this camera gives an IFoV of 30 microradians. Using the 0.75m critical dimension, a man will subtend 12 pixels at a range of 2.1km. The conclusion to be drawn from this example calculation is that identification of a man at multi-km ranges requires a lens in the 500mm focal length range.

Now take the case of an uncooled sensor, which has inherently less sensitivity than a cooled sensor with comparable optics and bigger pixels. A typical uncooled sensor has 25 micron pitch. This increased pixel size shortens the 500mm lens identification range to 1.25 km. But more importantly, uncooled lenses in the 500mm focal length range are simply impractical because the lenses have to have very low f/numbers in order to have thermal sensitivities comparable to cooled camera systems. A 500mm uncooled lens with f/1.6 has an objective diameter of 313mm, which is enormous and very expensive. The lenses can be so expensive that they negate much of the cost saving gained from using uncooled sensors over cooled ones. In fact, at this time the longest existing commercial uncooled lens is 367mm long. A 367mm lens combined with a 25 micron pitch uncooled camera gives a maximum identification range of only 920 meters.

The conclusion from this example is that extremely long range thermal imaging applications are best served by cooled camera systems. This is particularly true in the midwave band in humid atmospheric conditions.

Atmospheric conditions

Although thermal imaging cameras can see through total darkness, light fog, light rain and snow, the distance they can see is affected by these atmospheric conditions. Even in clear skies, inherent atmospheric absorption places limits on how far a particular infrared camera system can see. In essence, the farther an infrared signal must travel from the target to the camera, the more of that signal is lost along the way.

Rain and fog can severely limit the range of thermal imaging systems due to scattering of light off of droplets of water. Fog is a visible aggregate of minute water droplets suspended in the atmosphere at or near the surface of the earth, reducing horizontal visibility to less than 1km in many cases. It is created when the air temperature and the dew point of the air are nearly equal and sufficient condensation nuclei are present. There are different types of fog, and some fogbanks are denser than others because the water droplets have grown bigger through accretion. A thermal imaging camera will have more difficulty seeing through these dense types of fog, and its range will be reduced. The same goes for heavy rainfall and snow. Additionally, rain can reduce contrast because it will cool the surfaces of targets. Despite degraded performance in fog, rain and snow, thermal imaging cameras will still allow operators to see targets further than is possible with visible-light imaging systems.

Range is affected by many variables

In summary, there is no easy answer to the question "how far can I see with a thermal imaging camera?" It depends on a large number of environmental and system variables, including the nature of the target (parked vehicle versus running vehicle), the background (hot desert versus cold snow), and atmospheric conditions (clear skies versus fog). It also depends on the specific camera and lens combination you choose. The applications engineers at FLIR Systems can help you to determine the ranges at which you can detect various targets in various conditions with thermal imaging camera systems.

Nomographs

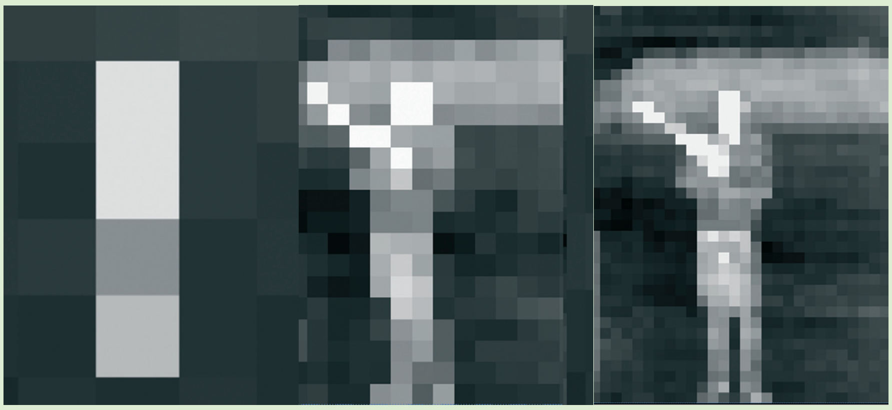
An excellent way to estimate how far you can see a target with a thermal imaging camera is to use a nomograph. A nomograph is a graphical calculator which represents numerical relationships between variables such as focal length, range and the number of pixels on target. The following two nomographs (for uncooled and cooled camera systems) are simplified models for estimating the range at which a man can be detected, recognized or identified. These models do not include atmospheric effects or thermal contrast – they assume very high contrast images acquired in clear conditions and can be considered to be upper limits on range based solely on geometry.

Example :

The Johnson Criteria assume that the critical dimension for a human being is 0.75 meters. To get DRI, you need 1.5 pixels, 6 pixels and 12 pixels across 0.75 meters in the object plane. That means:

1.5 pixels/0.75m = 2 pixels per meter
6 pixels/0.75m = 8 pixels/meter
12 pixels/0.75m = 16 pixels/meter

Let us assume a man is 1.8m by 0.5m. So the man should be covered by:



Detection =
3.6 pixels by 1 pixel
You can see something is there.

Recognition =
14.4 pixels by 4 pixels
You can see that a person is there.

Identification =
28.8 pixels by 8 pixels
You can see that the person is holding a rifle.

Images only intented to represent the concept.

Uncooled 320 x 240 detector with 25 micron pitch and 38 mm lens (19 mm lens with 2x doubler)

Pixels on target across height of man: 1.8 m

33 m

83 pixels

45 m

61 pixels

91 m

30 pixels

137 m

20 pixels

182 m

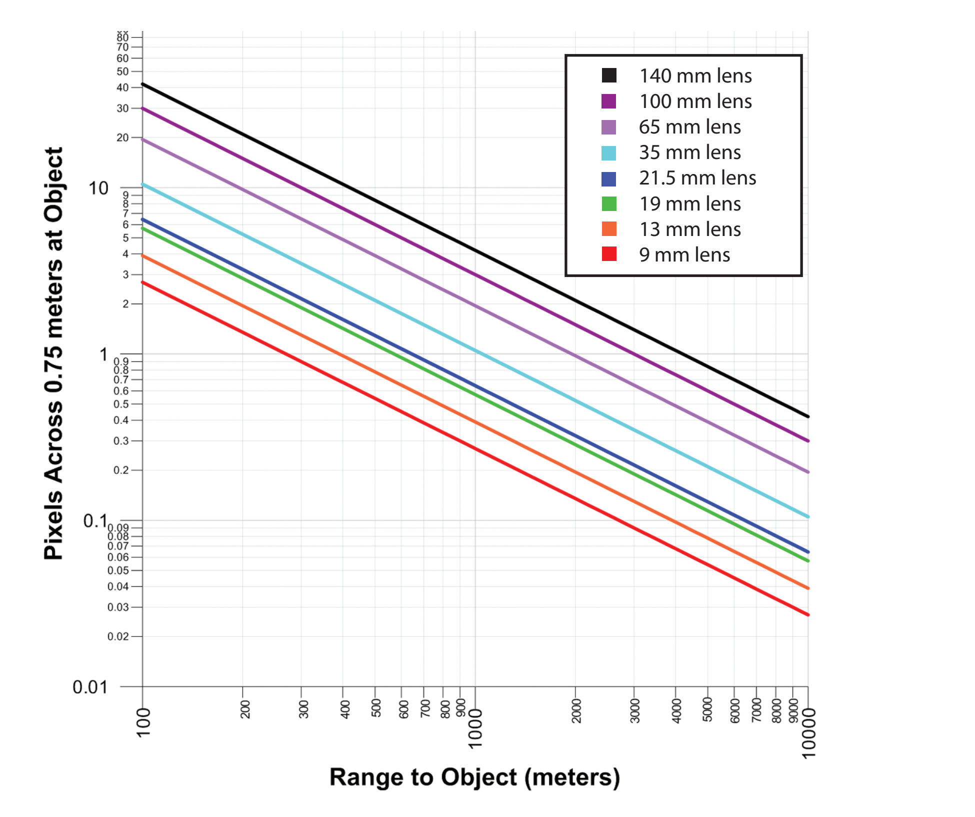
15 pixels

274 m

10 pixels

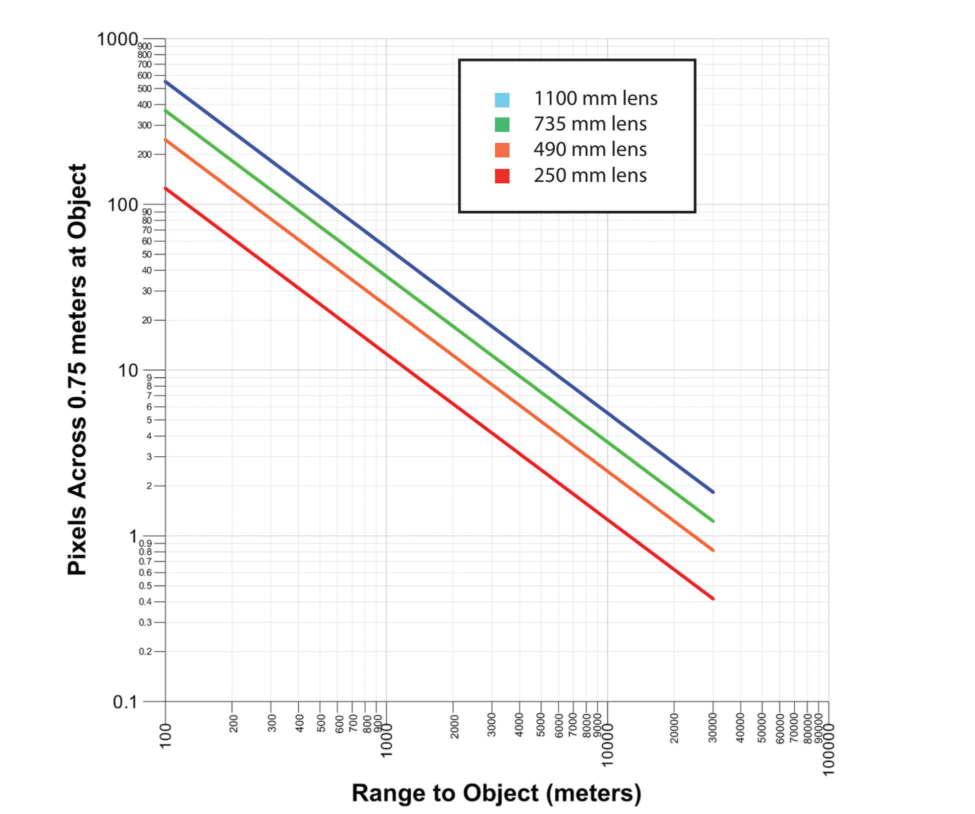
390 m

7 pixels



Nomograph:
uncooled 320 x 240 detector
with 25 micron pitch

Pixels across 0.75 m
critical dimension of
man-sized target
versus range



Nomograph:
cooled 640 x 480 detector
with 15 micron pitch

Pixels across 0.75 m
critical dimension of
man-sized target
versus range

The FLIR Systems HRC-U or HRC-S can detect potential threats at extremely long ranges.

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More information about thermal imaging cameras can be obtained from:

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