MANUAL

MCS640 Thermal Imager

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Contents

1 General

1.1 Information about the user manual

Congratulations on choosing this high quality and highly efficient LumaSense MCS640 Thermal Imager.

This manual provides important information about the instrument and can be used as a work of reference for installing, operating, and maintaining your instrument. It is important that you carefully read the information contained in this manual and follow all safety procedures before you install or operate the instrument.

To avoid handling errors, keep this manual in a location where it will be readily accessible.

1.1.1 Legend

Note: The note symbol indicates tips and useful information in this manual. All notes should be read to effectively operate the instrument.

Warnings and Cautions: The general warnings and cautions symbol signifies the potential for bodily harm or damage to equipment.

1.2 Operator training

To best understand and utilize the measurements and images derived from the operation of this instrument, the operator should understand the basics of heat transfer and infrared radiation theory. Notes on these basics can be found in Chapter 4 of this manual. Qualified personnel should provide education and training in these subjects.

Caution: The MCS640 instrument is a sealed unit. Do not attempt to open the instrument housing as this will void the LumaSense warranty.

Please refer to the warranty statement found in Section 1.4 of this manual.

1.3 Regulatory information

This section describes how the Infrared camera complies with regulations in certain regions. Any modifications to the Infrared camera not expressly approved by the manufacturer could void the authority to operate the Infrared camera in these regions.

USA

This Infrared camera generates, uses, and can radiate radio frequency energy and may interfere with radio and television reception. The Infrared camera complies with the limits for a Class B digital device used exclusively as industrial or commercial test equipment, pursuant to Part 15 Subpart B Sec. 15.103 c. of the FCC Rules.

These limits are designed to provide reasonable protection against harmful interference. However, there is no guarantee that interference will not occur in a particular installation.

1.3.1 General conditions of operation

Persons operating intentional or unintentional radiators shall not be deemed to have any vested or recognizable right to continued use of any given frequency by virtue of prior registration or certification of equipment, or, for power line carrier systems, on the basis of prior notification of use pursuant to Sec. 90.63(g) of this chapter.

Operation of an intentional, unintentional, or incidental radiator is subject to the conditions that no harmful interference is caused and that interference must be accepted that may be caused by the operation of an authorized radio station, by another intentional or unintentional radiator, by industrial, scientific and medical (ISM) equipment, or by an incidental radiator.

The operator of a radio frequency device shall be required to cease operating the device upon notification by a Commission representative that the device is causing harmful interference. Operation shall not resume until the condition causing the harmful interference has been corrected.

1.4 Limit of liability and warranty

All general information and notes for handling, maintenance, and cleaning of this instrument are offered according to the best of our knowledge and experience.

LumaSense Technologies is not liable for any damages that arise from the use of any examples or processes mentioned in this manual or in case the content of this document should be incomplete or incorrect. LumaSense Technologies reserves the right to revise this document and to make changes from time to time in the content hereof without obligation to notify any person or persons of such revisions or changes.

All instruments from LumaSense Technologies have a regionally effective warranty period. Please check our website at http://info.lumasenseinc.com/warranty for up-to-date warranty information. This warranty covers manufacturing defects and faults which arise during operation, only if they are the result of defects caused by LumaSense Technologies.

The *Windows compatible software* was thoroughly tested on a wide range of Windows operating systems and in several world languages. Nevertheless, there is always a possibility that a Windows or PC configuration or some other unforeseen condition exists that would cause the software not to run smoothly. The manufacturer assumes no responsibility or liability and will not guarantee the performance of the software. Liability regarding any direct or indirect damage caused by this software is excluded.

The warranty is VOID if the instrument is disassembled, tampered with, altered, or otherwise damaged without prior written consent from LumaSense Technologies; or if considered by LumaSense Technologies to be abused or used in abnormal conditions. There are no user-serviceable components in the instrument.

1.5 Unpacking the instrument

Before shipment, each instrument is assembled, calibrated, and tested at the LumaSense Factory. When unpacking and inspecting your system components, you need to do the following:

1. Check all materials in the container against the enclosed packing list.

   LumaSense Technologies cannot be responsible for shortages against the packing list unless a claim is immediately filed with the carrier. Final claim and negotiations with the carrier must be completed by the customer.

2. Carefully unpack and inspect all components for visible damage. If you note any damage or suspect damage, immediately contact the carrier and LumaSense Technologies, Inc.

3. Save all packing materials, including the carrier's identification codes, until you have inspected all components and find that there is no obvious or hidden damage.

Note: LumaSense encourages you to register your product with us to receive updates, product information, and special service offers: http://info.lumasenseinc.com/registration.

1.6 Service request, repair, or support

Contact LumaSense Technologies Technical Support in case of a malfunction or service request. Provide clearly stated details of the problem as well as the instrument model number and serial number. Upon receipt of this information, Technical Support will attempt to locate the fault and, if possible, solve the problem over the telephone.

If Technical Support concludes that the instrument must be returned to LumaSense Technologies for repair, they will issue a Return Material Authorization (RMA) number.

Return the instrument upon receipt of the RMA number, transportation prepaid. Clearly indicate the assigned RMA number on the shipping package exterior. Refer to Section 1.7, Shipments to LumaSense for Repair, for shipping instructions.

Technical Support can be contacted by telephone or email:

Santa Clara, California

- Telephone: +1 408 727-1600 or +1 800 631 0176
- Email: support@lumasenseinc.com

Frankfurt, Germany

- Telephone: +49 (0) 69 97373 0
- Email: eusupport@lumasenseinc.com

1.7 Shipments to LumaSense for repair

All RMA shipments of LumaSense Technologies instruments are to be prepaid and insured by way of United Parcel Service (UPS) or preferred choice. For overseas customers, ship units air-freight, priority one.

The instrument must be shipped in the original packing container or its equivalent. LumaSense Technologies is not responsible for freight damage to instruments that are improperly packed.

Contact us to obtain an RMA number (if one has not already been assigned by Technical Support). Clearly indicate the assigned RMA number on the shipping package exterior.

Send RMA Shipments to your nearest technical service center:

Worldwide customers (except Europe) should send RMA Shipments to:	European customers should send RMA Shipments to:
Santa Clara, California	**Frankfurt, Germany**
LumaSense Technologies, Inc. 3301 Leonard Court Santa Clara, CA 95054 USA Telephone: +1 408 727 1600 +1 800 631 0176	LumaSense Technologies GmbH Kleyerstr. 90 60326 Frankfurt Germany Telephone: +49 (0) 69 97373 0
Email: support@lumasenseinc.com	**Email:** eusupport@lumasenseinc.com

1.8 Transport, packaging, storage

With faulty shipping, the instrument can be damaged or destroyed. To transport or store the instrument, please use the original box or a box padded with sufficient shock-absorbing material. For storage in humid areas or shipment overseas, the device should be placed in welded foil (ideally along with silica gel) to protect it from humidity.

1.9 Disposal / decommissioning

Inoperable thermal imagers must be disposed of in compliance with local regulations for electro or electronic material.

2 Introduction

The MCS640 represents another milestone in innovative infrared thermal imaging. Designed with advanced maintenance-free electronics and industrial protective packing, the MCS640 offers unparalleled accuracy for demanding industrial and scientific applications. With an unmatched array of protective accessories, the MCS640 demonstrates LumaSense's commitment to long-term trouble-free operation of these instruments. The MCS640 quickly measures temperature without contact in even the most adverse environments. Its compact design provides for easy integration into standard enclosures for use in harsh environments and its full array of optional lenses meet the needs of most applications.

The technique of thermal imaging, or thermography, is based on well-established technology and has been used for a wide variety of applications. However, implementing a systems approach for thermal process applications requires detailed knowledge of the specific application, available thermal imagers and thermal scanners, existing controls platform, and software requirements, etc. As such, we have a full staff of engineering and software specialists available for the design and development of comprehensive turn-key systems for all customer applications. Experience in many different thermal applications is the backbone of our designs and short-term turnaround for specialized software and custom camera configurations is our specialty.

2.1 System Overview

The MCS640 is intended to be integrated with the appropriate application-specific imaging components for use in process control, nondestructive testing, and diagnostic applications. It provides real-time digital image transfer and control using Gigabit Ethernet and provides an option for remote monitoring through a Local Area Network. As such, the MCS640 thermal imaging system can be used as a machine vision system, operator-based temperature monitoring system, fully automatic temperature control system, or stand-alone smart sensor for alarm temperature control.

Note: The MCS640 is designed to operate on a 32 or 64-bit Windows™ based computer with the following (minimum) components: Dual Core 1.5 GHz or faster processor, 4 GB RAM (running at 1600 MHz), Dedicated Video Card with 1 GB of 900 MHz DDR3 dedicated RAM, 7200 RPM Hard Drive with a 16 MB buffer and using a 3.0 GB/sec SATA bus, Gigabit Ethernet card that supports Jumbo Packets up to 9014 bytes.

2.1.1 System Features

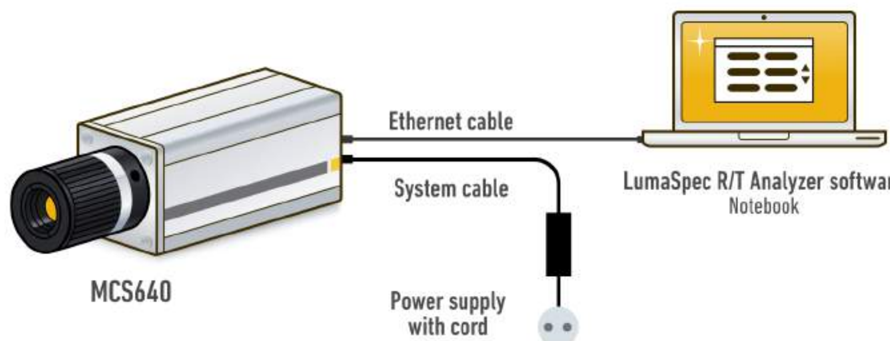
- Rugged MCS640 Thermal Imager described herein
- LumaSpec R/T software (see LumaSpec R/T user manual) including:
  - Advanced image processing core
  - Image capture and playback
  - Histograms and trending
  - Regions of interest and alarm functionality
  - Integration with other devices in the process or other systems (PLCs, computers, SCADA and Distributed Control Systems (DCSs), other sensing devices, actuators, etc.)
  - Archiving and web server
  - Report writing

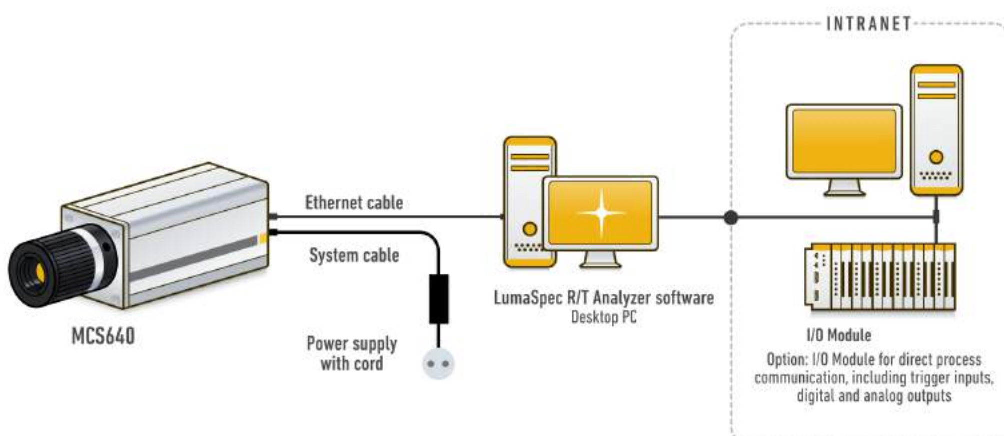
- Housings and enclosure options, matched to the harsh environment (explosive, hazardous, outdoor, etc.)
- Communication cable and power supply
- Start-up support

LumaSense engineering staff and sales consultants follow a system approach to online thermal processing control. They have specific expertise and technical skills required to specify and integrate the appropriate application-specific imaging components with your existing control platform. LumaSense takes the ultimate responsibility for the thermal imaging system meeting your design specifications and saving you time, cost, and allocation of in-house resources.

2.1.2 System Configuration

LumaSense's thermal imagers offer several configuration options. The system can be set up by connecting the camera to a network device (switch) or by connecting the camera directly to a dedicated computer using a cross-over Ethernet cable. Additionally, the camera can be used with a desktop PC or with a notebook PC for a mobile measuring system.





2.2 Scope of Delivery

2 m Ethernet cable, 2 m power supply cable, power supply unit (100 to 240 VAC, 47 to 63 Hz), mounting adapter, lens cap, carrying case, quick start guide, and LumaSpec R/T Viewer software.

2.3 Technical Data

Performance

Temperature Ranges:	MCS640/I1 Filter 600 to 1600 °C (MB16) or 800 to 3000°C (MB30) in up to 4 sub-ranges MCS640/I5 Filter 600 to 1600 °C (MB16) or 800 to 3000°C (MB30) in up to 4 sub-ranges
Sub Ranges:	MB16: 600 to 850, 700 to 1000, 850 to 1250, 1100 to 1600 MB30: 800 to 1150,1000 to 1500, 1350 to 2050, 1900 to 3000
Spectral Ranges:	MCS640/I1 Filter 850 nm (I1 filter) MCS640/I5 Filter 780 to 1080 nm (I5 filter)
Measurement Accuracy:	+/- 0.5% of reading in °K
Repeatability	0.1% of measured value in °K + 1°K
Image Update Rate:	60 Hz (fps; frames per second)
A/D Resolution:	16 bit
Detector:	640 x 480 pixel; Silicon
Emissivity Correction:	10.0 to 100.0% adjustable via interface in steps of 0.1% (for full camera picture)
Transmittance	10 to 100 % (in application software)
Sensitivity/NETD	MCS640/I1 Filter 1° at 600 °C MCS640/I5 Filter 1° at 600 °C

Optical Specifications

Field of View:	21° (H) x 16° (V) (standard lens)
Focus Range:	30 cm to infinity

Environmental Specifications

Protection Class:	IP65 (IEC 60529); NEMA 4
Shock Resilience:	30G (IEC60068-2-29/JIS C 0042)
Vibration Resilience:	3G (IEC60068-2-6/JIS C 0040)
Operating Temperature:	0 to 50 °C
Storage Temperature:	-40 to 70 °C
Relative Humidity:	None condensing conditions
Weight:	0.7 kg (1.5 lbs)
Operating Position:	Any orientation
Housing:	Aluminum extrusion
Dimensions:	2.19 in x 2.46 in x 6.5 in (55.6 mm x 62.5 mm x 165.1 mm)
CE-label	According to EU directives about electromagnetic immunity

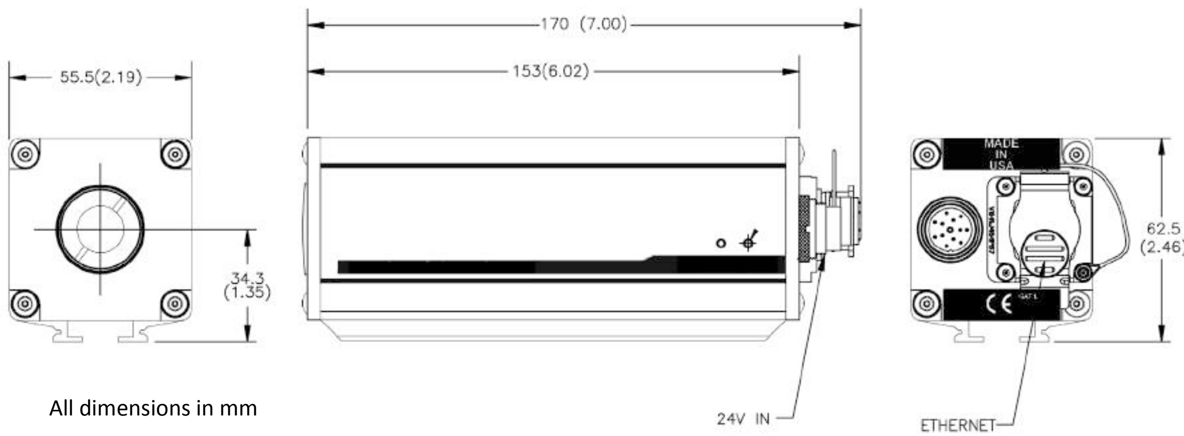
Interface

Analog:	None
Digital:	Gigabit Ethernet (1000 MBit/s)
Optics:	Manual focus
Connections:	12 pin power connector; RJ45 Ethernet connector

Electrical

Power Supply:	24VDC, 1A
Power Consumption:	10W Typical, 13W Max
Isolation:	Power supply and digital interface are galvanically isolated from each other

2.4 Dimensions



All dimensions in mm

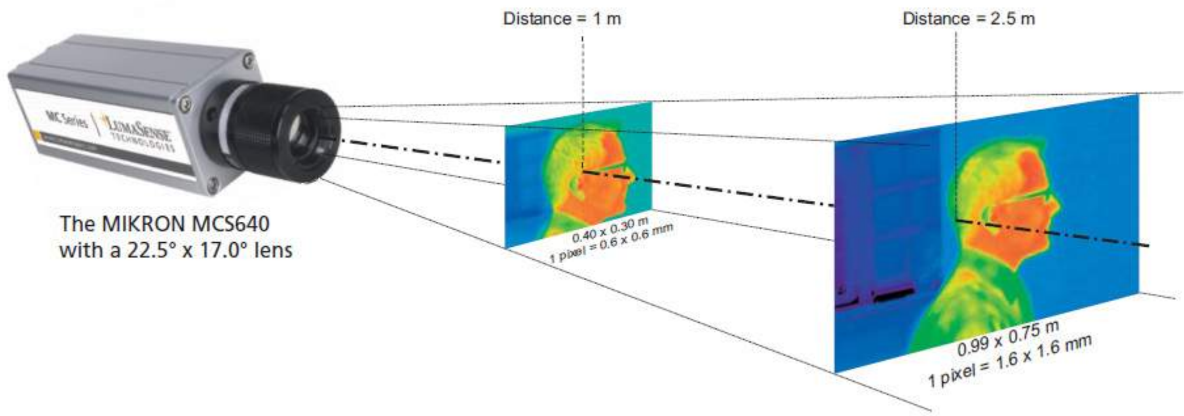
Lens Length vs. HFOV	Lens Diameter	3.5°	5.4°	10.8°	22.5°	33.3°	41.0°
Filter code I5 (without filter adaptor)	44 mm	65.5 mm	38.5 mm	25.5 mm	27.0 mm	27.0 mm	31.5 mm
Filter code I1, I2, I3, I4, I8 and V (including filter adaptor)	44 mm	90.5 mm	63.5 mm	50.5 mm	52.0 mm	52.0 mm	56.5 mm

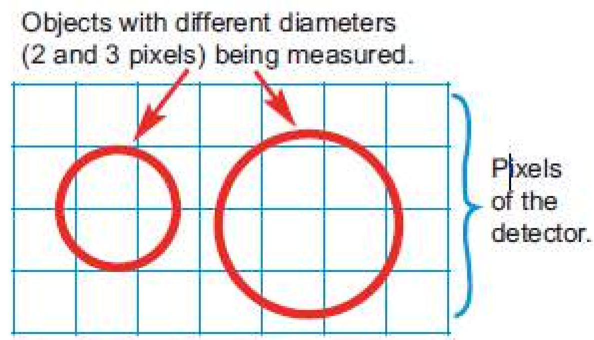
2.5 Optics

A wide range of alternative lenses are available for the MCS640, making the thermal imager suitable for most applications. The table and picture below show the correlation between the measurement distance, different optics, and the size of the measurement fields.

Distance of object [m]	Measurement field W x H [m]					
	3.5° x 2.6°	5.4° x 4.0°	10.8° x 8.1°	22.5° x 17.0°	33.3° x 25.3°	40.4° x 30.9°
0.30	-	-	-	-	-	-
0.60	-	-	-	-	-	-
1.00	0.06 x 0.05	0.19 x 0.14	0.19 x 0.14	0.40 x 0.30	0.60 x 0.45	0.74 x 0.55
1.50	0.09 x 0.07	0.14 x 0.10	0.28 x 0.21	0.60 x 0.45	0.90 x 0.67	1.10 x 0.83
2.50	0.15 x 0.11	0.24 x 0.17	0.47 x 0.35	0.99 x 0.75	1.50 x 1.12	1.84 x 1.38
10.00	0.61 x 0.45	0.94 x 0.70	1.91 x 1.43	3.98 x 2.99	5.98 x 4.99	7.36 x 5.53

Note: Distances in the table may not apply to some high-temperature situations. Be sure to consult the Applications Department to determine the proper distance for your application.

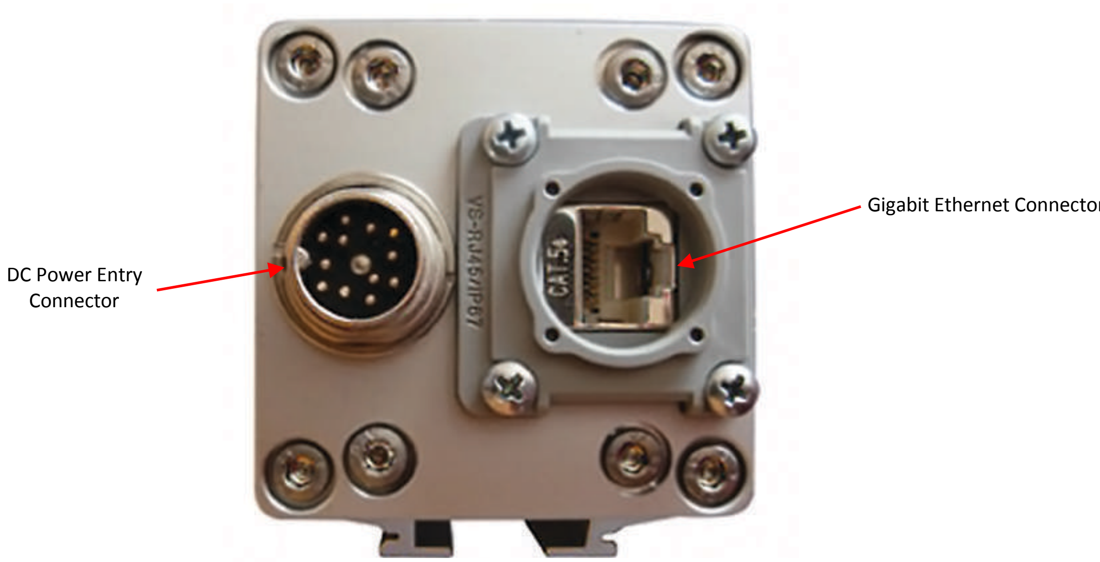




Note: The size of the measured object must be at least 3 x 3 pixels to guarantee precise temperature determination. This ensures that at least one pixel of the detector is completely covered.

2.6 Camera Interface

The rear panel of the MCS640 supports connectors for the Gigabit Ethernet and DC Power input.



Rear Panel MCS640 Camera

2.7 Lenses

The MCS640 is a process camera that has a full array of optional lenses available to meet the needs of most applications. However, because of the extreme and application-specific nature of the camera system, it is necessary that the appropriate lens be fitted and calibrated at the LumaSense Factory according to the application requirements.

Contact LumaSense for further information on lens considerations for the MCS640 thermal imaging system.

The table and picture shown in Section 2.5 shows the correlation between the measurement distance, different optics, and the size of the measurement fields.

Caution: Do not use thinners, benzene, or other chemicals to clean the lens as these will damage the lens coating.

2.8 Environmental Conditions

The MCS640 has an internal temperature sensor in the detector and is designed to withstand ambient temperatures from 0 °C to 50 °C without a temperature-controlled enclosure. The temperature reading can be displayed and read by image processing software via the Gigabit Ethernet connection.

In addition to temperature requirements, other environmental factors must also be considered when installing the MCS640 thermal imaging system. For example, if the camera is going to be mounted in a harsh environment, certain precautions must be taken to secure and protect the system from its surroundings.

Contact LumaSense for further information on environmental considerations and protective enclosures for the MCS640 thermal imaging system.

3 Getting Started

Lumasense MCS640 thermal imagers are designed to allow you to quickly be up and running to gain valuable insight into your thermal processes. As such, the camera is assembled, calibrated, and tested at the LumaSense Factory and is delivered with the necessary components to create a fully-operational system.

Assemble the system by connecting the cables as shown on the System Configuration and Wiring drawing supplied with the system.

Caution: Because the MCS640 system is designed for specific application situations, it is imperative that you configure your system in accordance with the electrical diagrams supplied with your system.

In addition, the MCS640 camera is a Gigabit Ethernet camera. In order to ensure all frames are transferred and reconstructed successfully, the following hardware needs to be used at minimum:

- Cat 5e or Cat 6 network cable
- Network card with 1.0 Gbps transfer rate
- i3, i5 or i7 CPU
- Accelerated video adapter (ATI, Nvdia etc.)
- Windows XP, Vista, 7, or 8 operating system

3.1 Making the Connections

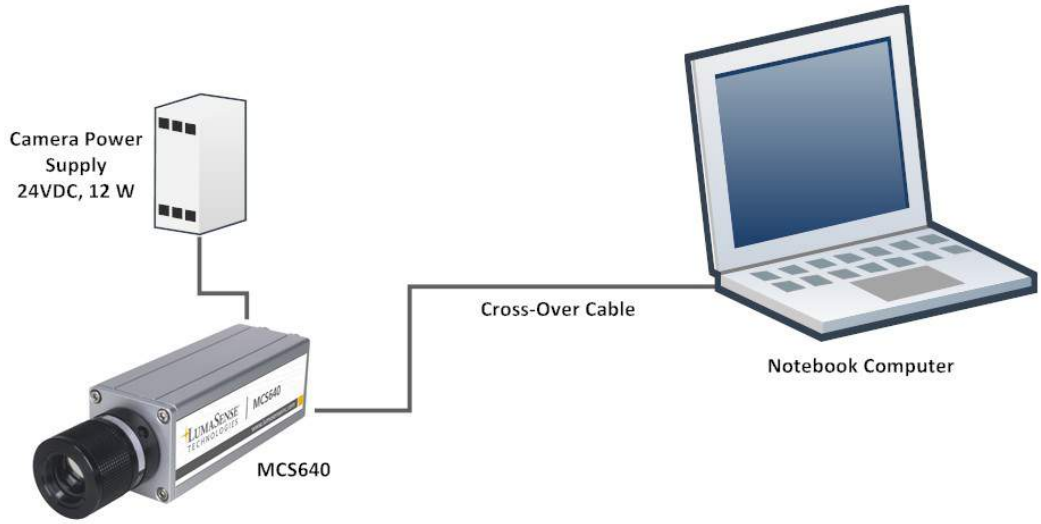
3.1.1 Connecting the Power

Insert the power cable into the DC In terminal located on the rear panel of the camera.

3.1.2 Connecting the Ethernet Cable

In order for the MCS640 system to operate correctly, the supplied hardware must be properly attached to the computer and power supplied to the various parts of the system. Typically, the system is set up by either connecting the camera to a network device (switch) or by connecting the camera directly to a dedicated computer using a cross-over Ethernet cable.

Connecting the Camera to a Dedicated Computer

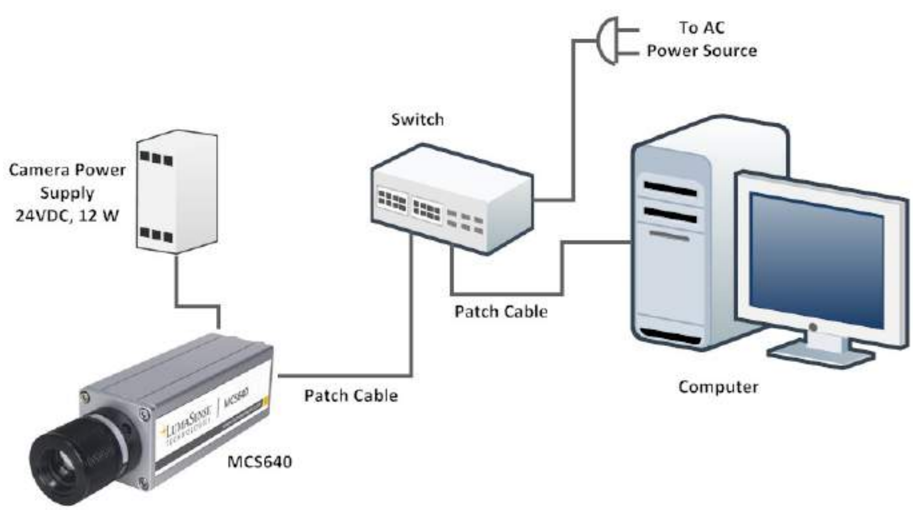


Connecting the MCS640 to a computer using a crossover cable

<u>*To connect the camera to a dedicated computer:*</u>

1. Connect one end of the RJ45 (Ethernet) Cross-over cable to the Ethernet port on the camera and the other end to the computer. The MCS640 requires a Gigabit Ethernet network adapter (see the software manual for a list of supported adapters). All cabling should be Cat5e or Cat 6.
2. Connect the camera power supply to the camera.
3. Turn on the computer to connect the camera to the computer.
4. Consult Section 3.2 Installing the Software.

Connecting the Camera to a Network Device



Connecting the MCS640 to a computer using a straight cable

To connect the camera to a network device:

1. Connect one end of an RJ45 Ethernet patch cable to the Ethernet port on the camera and the other end to the switch.
2. Connect one end of another RJ45 Ethernet patch cable to your computer and the other end to the switch.
3. Connect the camera power supply to the camera.
4. Turn on the computer.
5. Consult Section 3.2 Installing the Software.

Note: The MCS640 requires a Gigabit Ethernet network adapter. The appropriate PCI/Gigabit Ethernet card (Express Card, PCI, or PCI Express Card) is selected at the time of ordering and supplied with the camera. All cabling should be Cat5e or Cat 6.

3.2 Installing the Software

LumaSense's thermal imaging software provides you with all of the necessary executables and support files needed for remote camera control operations.

To install the software:

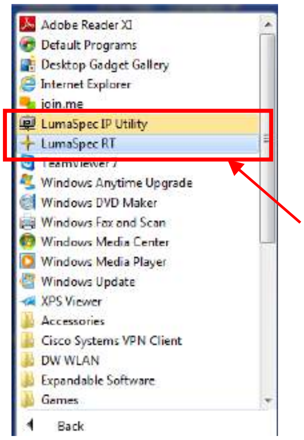
Note: These instructions use the LumaSpec™ R/T Control Multi 24 camera package. Screenshots of your software may vary slightly.

1. Close all programs on your PC.
2. Insert the disc that came with your camera into your optical drive.
3. Follow the on screen instructions to install the software. The installation will complete within a few seconds.

Note: If you are using a disc and do not get on screen instructions, it could mean that your auto play feature is disabled. In this case, open the disc files and right click the **LumaSenseInstall.exe file** and click **Run as Administrator.**

4. If using Windows XP or Vista, you will need to restart your system. A system restart is not required for Windows 7 or higher.

5. To ensure the software is installed correctly, Click **Start** (Windows Icon) > **All Programs** > **LumaSense IP utility** and **LumaSpec R/T** (or similar software) should be present as shown in the screen shot below.



For information on using the software, refer to the software manual that came with your system.

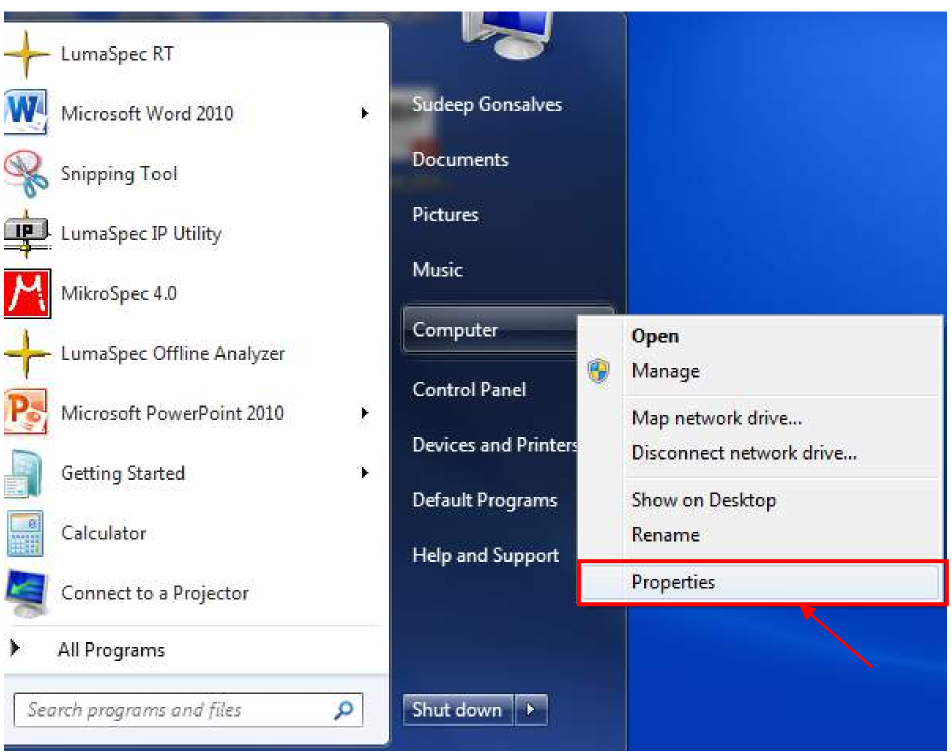
3.2.1 Optimize the Network Interface Card

The next step is to optimize the network interface card.

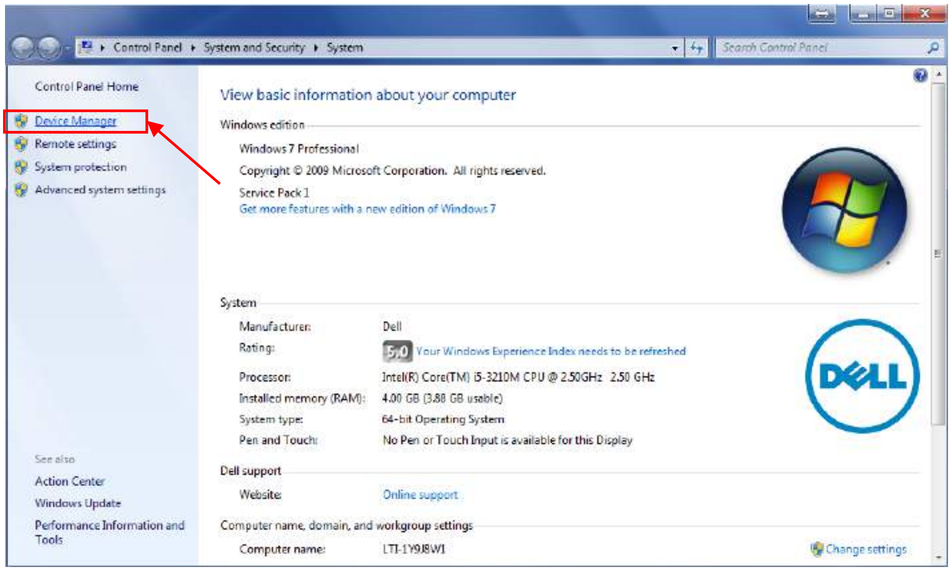
Note: Your instructions may vary slightly based upon which version of Windows you are using. These instructions were written using Windows 7.

To optimize the network interface card:

1. Access the network interface card by clicking **Start**, right clicking on **Computer**, and then select **Properties**.

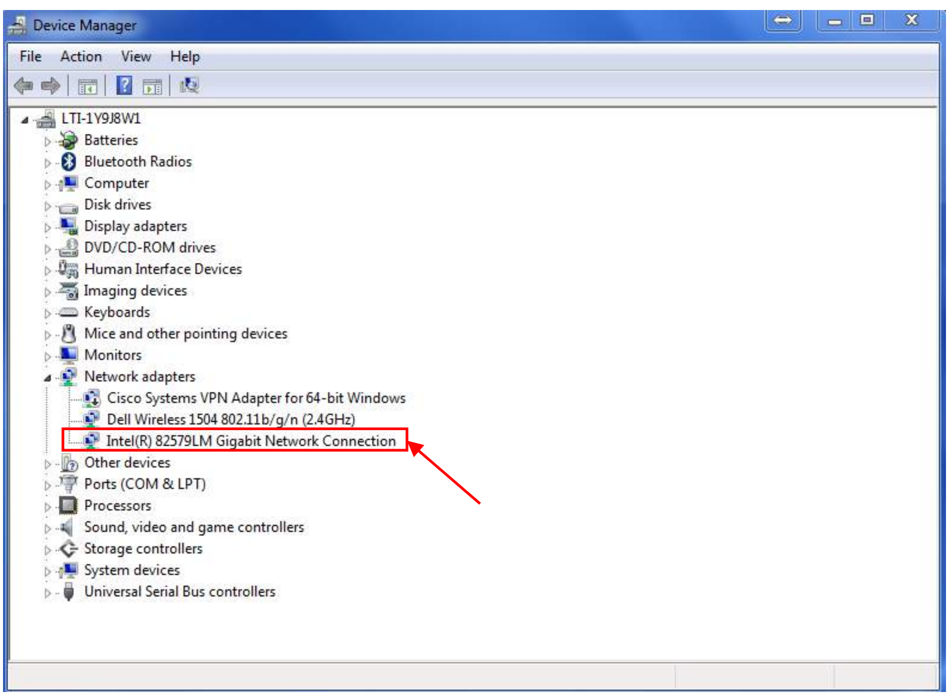


2. The **System Properties** screen will display. Click **Device Manager** at the top left of the screen.

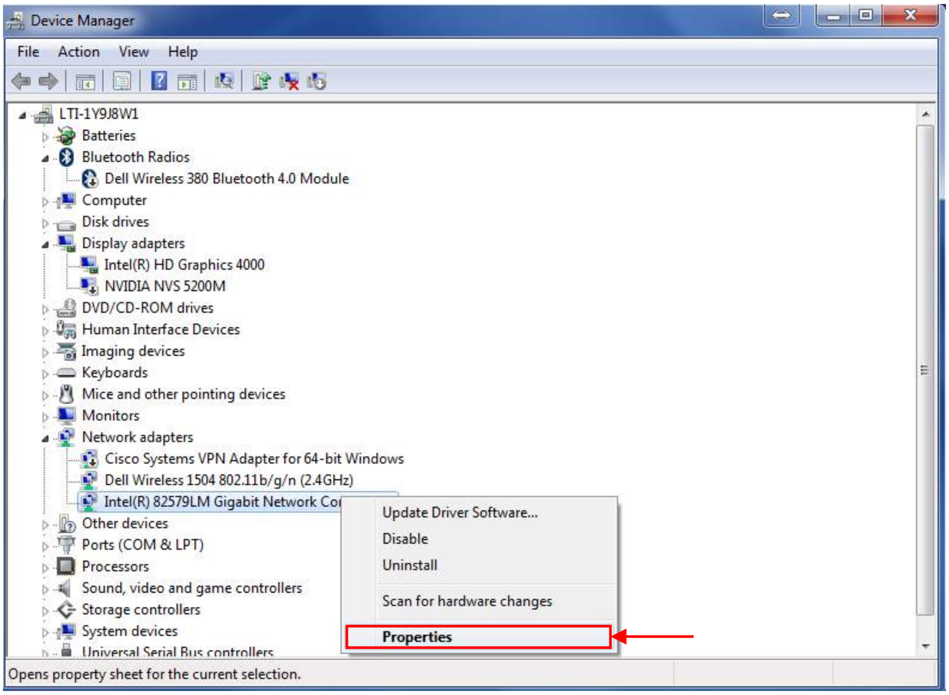


3. Click the arrow next to **Network adapters** to expand the list and access the network interface card.

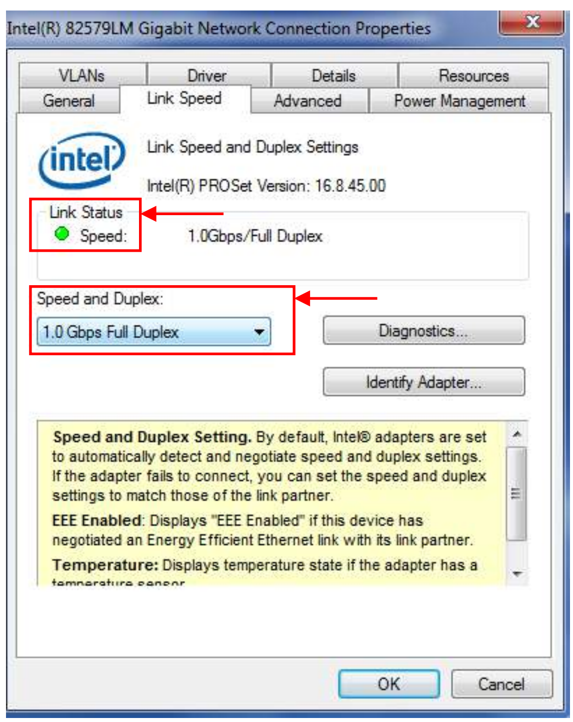
Note: Some computers may list more than one network interface card. Mark sure you select the network interface card on which the camera is connected.



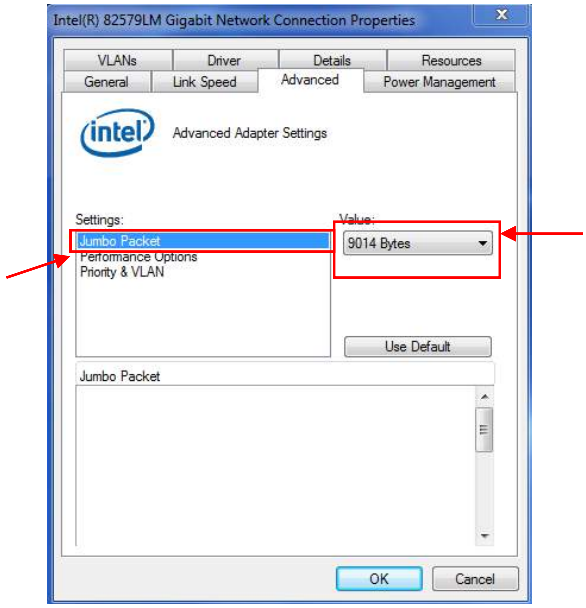
4. Right click on the network interface card on which the camera is connected and select **Properties.**



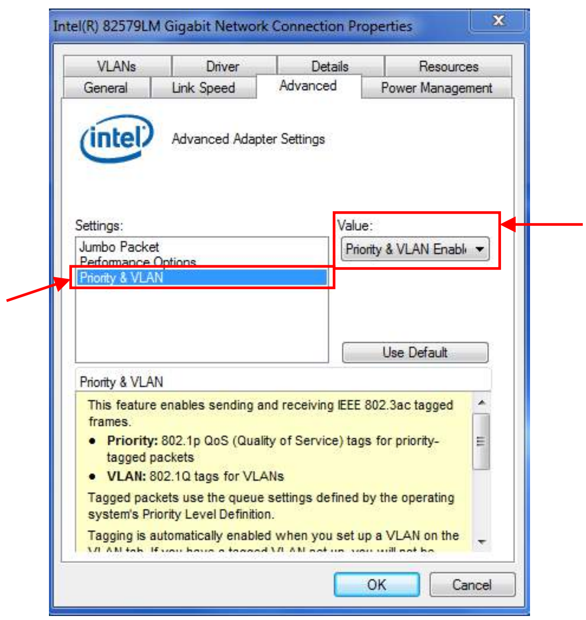
5. In the **Link Speed** tab, use the drop down box under **Speed and Duplex** to select **1.0 Gbps/full duplex.** If the camera is already connected and powered up, the **Link Status** LED will be green, as shown below.



6. Click on the **Advanced** tab and select **Jumbo** packets in the **Settings** box on the left. Using the drop down box under **Value**, select **9014 Bytes**.



7. Verify the **Priority & VLAN** is set to **Enabled** by clicking on **Priority & VLAN** and ensure **Priority & VLAN Enabled** is selected in the drop down box under **Value**.



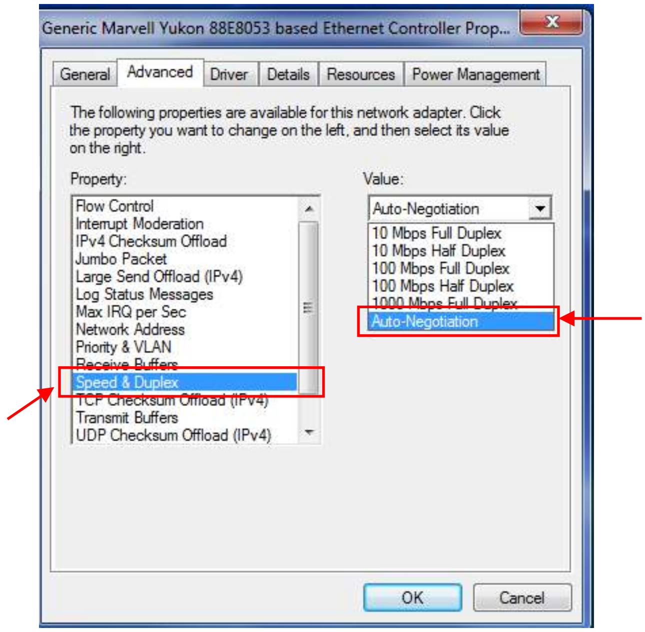
Note: Not all network adapters have this feature.

8. Click **OK** to save these settings.

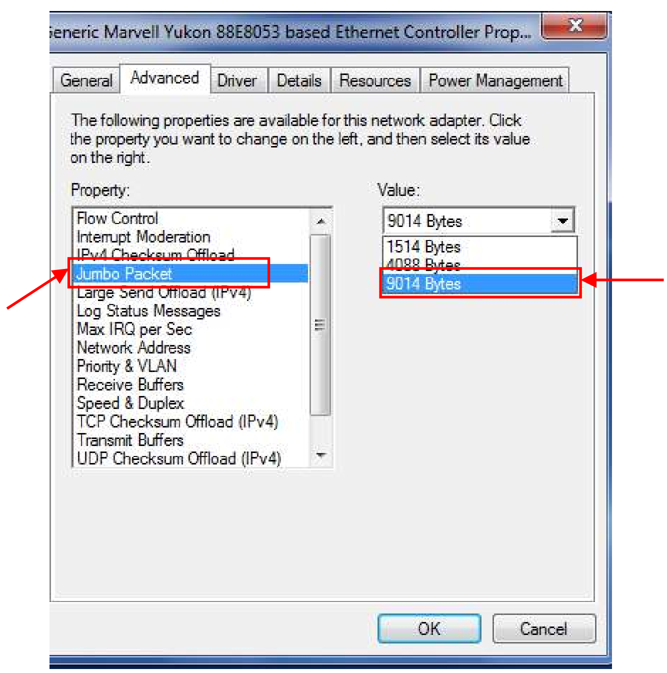
Note: Since there are different types of Ethernet controllers, the tabs on the Ethernet controller properties window may be different. Another example follows.

Alternate method to optimize the network interface card settings:

1. Complete steps 1 to 4 above.
2. Click the **Advanced** tab and select **Speed & Duplex** from the **Property** box on the left. Select **1.0 Gbps Full Duplex** (preferred) or **Auto-Negotiation**.



3. Select **Jumbo Packets** from the **Property** box on the left. Select **9014 Bytes.**

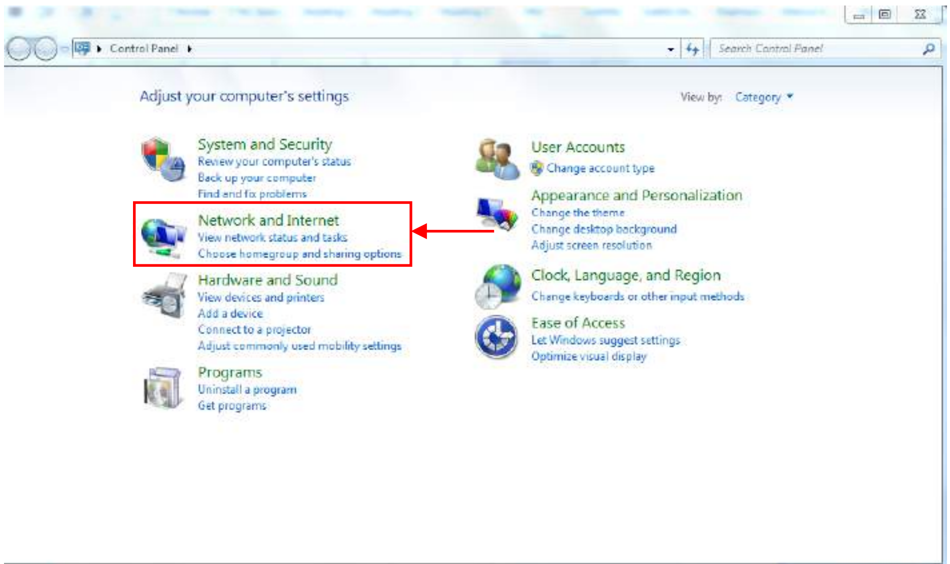


4. Click **OK** to save these settings.

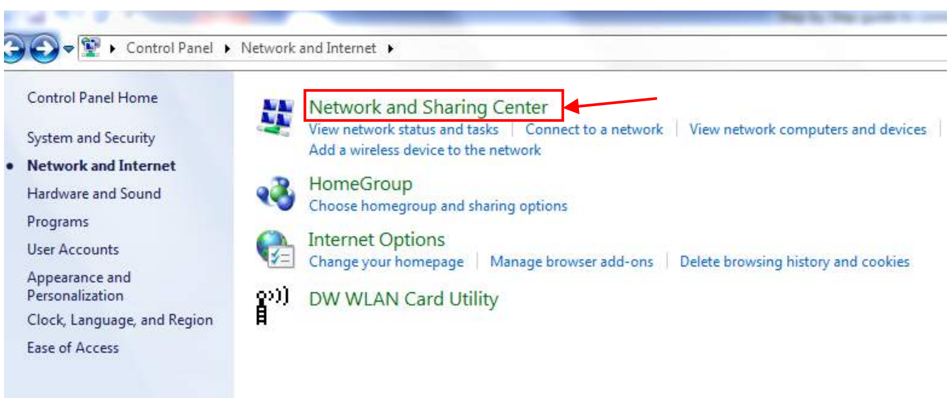
3.2.2 Set the IP Address

Note: Your instructions may vary slightly based upon which version of Windows you are using. These instructions were written using Windows 7.

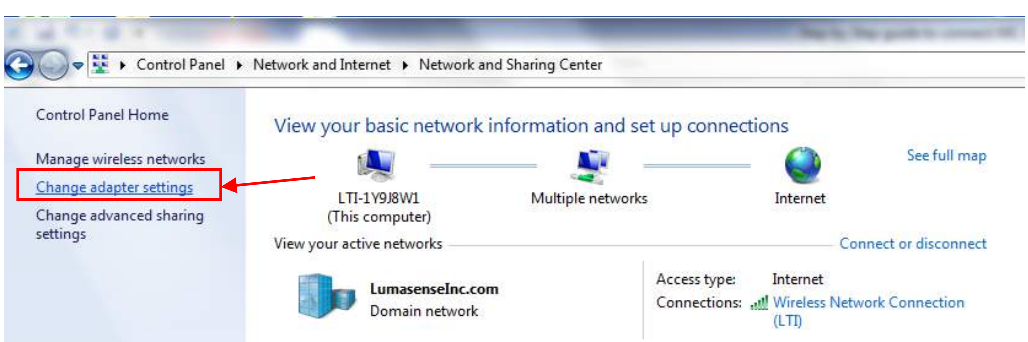
1. Access **Network and Internet Settings** by clicking **Start**, selecting **Control Panel**, and selecting **Network and Internet**.



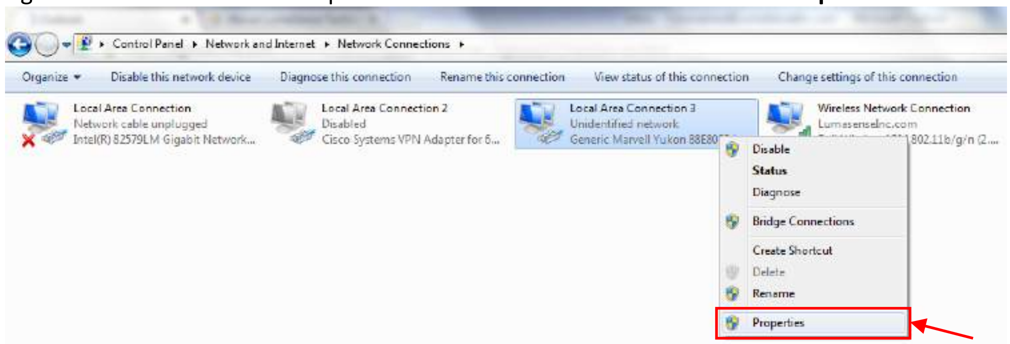
2. Click on **Network and Sharing Center.**



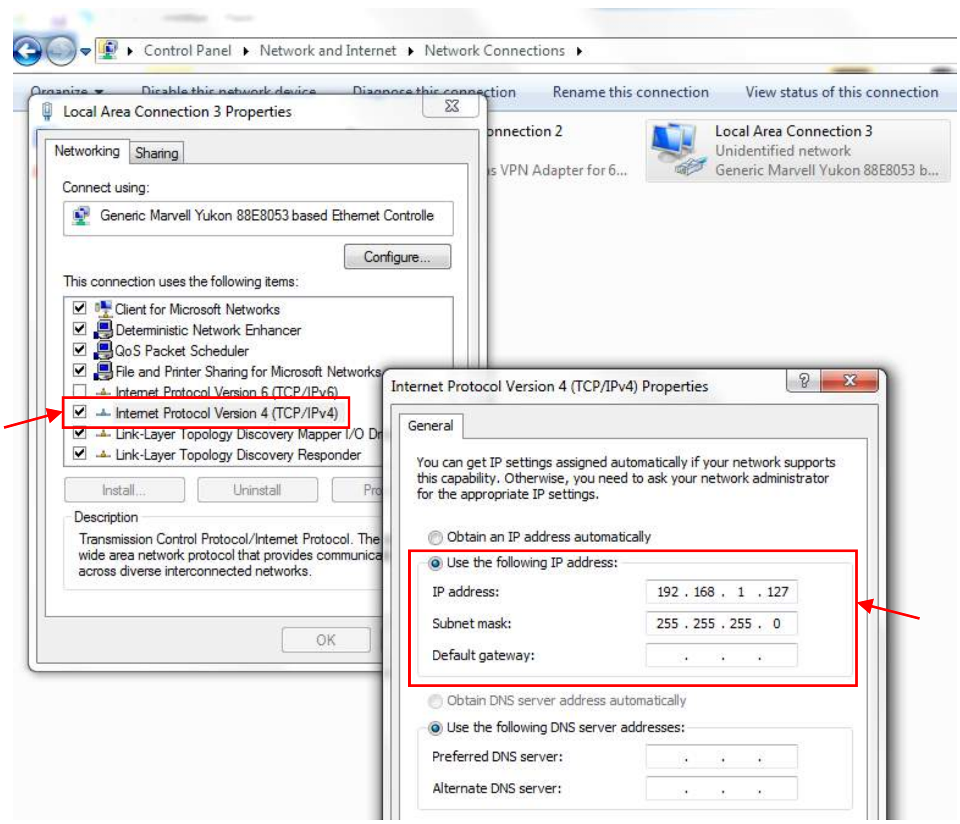
3. Click **Change adapter settings**.



4. Right click on the network adapter the camera is connected to and click **Properties**.



5. Click **Internet Protocol Version 4 (TCP/IP)** and click **Properties**. Next, select **Use the following IP address** radio button and enter an IP address. The IP address could be any number in the form of 192.168.1.127 and subnet mask 255.255.255.0. Click **OK**.

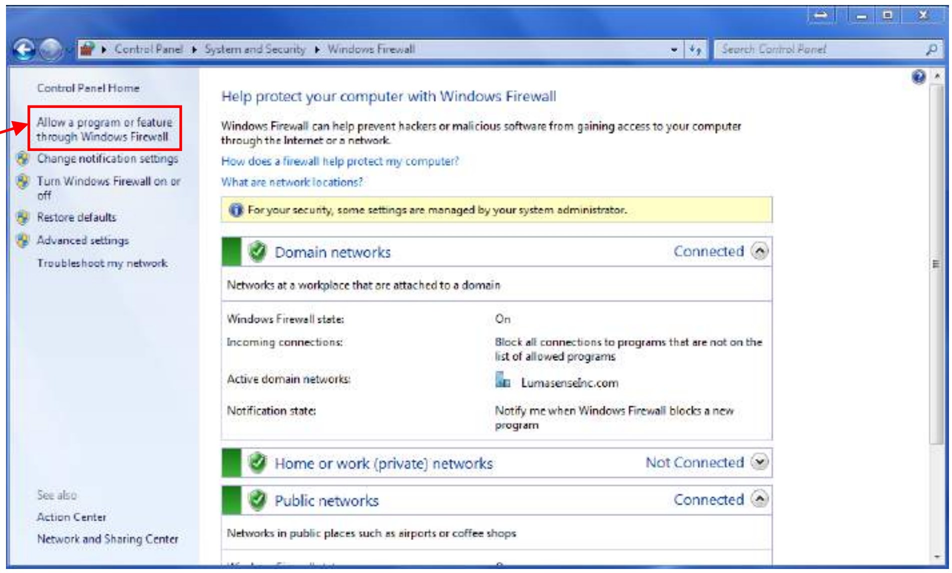


3.2.3 Configure the Windows Operating System

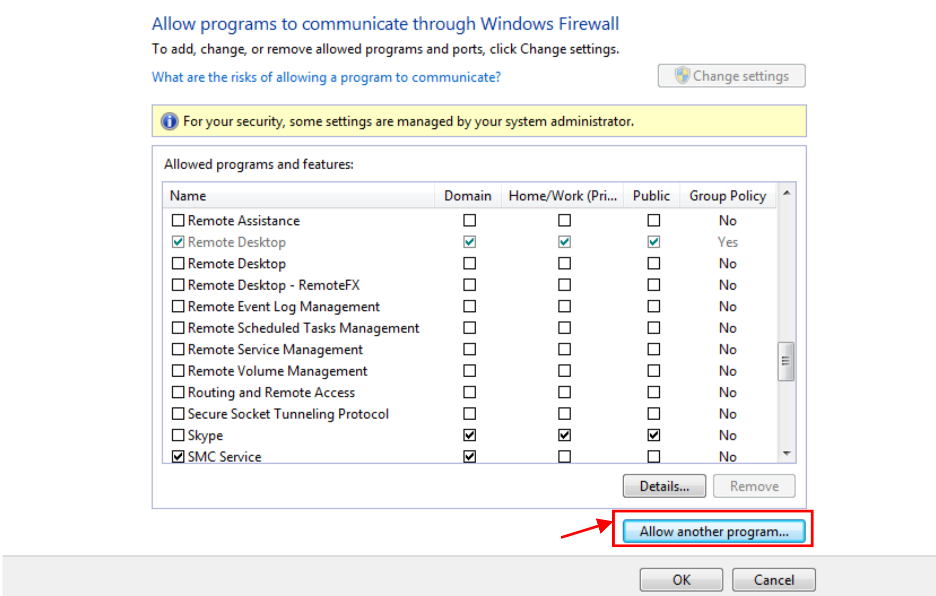
You need to add LumaSpec R/T to the list of “Allowed programs” to prevent the Windows Firewall from blocking incoming packets.

To add LumaSpec R/T software to the list of “Allowed programs”:

1. Click **Start** > **Control Panel** > **Systems and Security** > **Windows Firewall**.
2. Click **Allow a program or feature through Windows Firewall**.



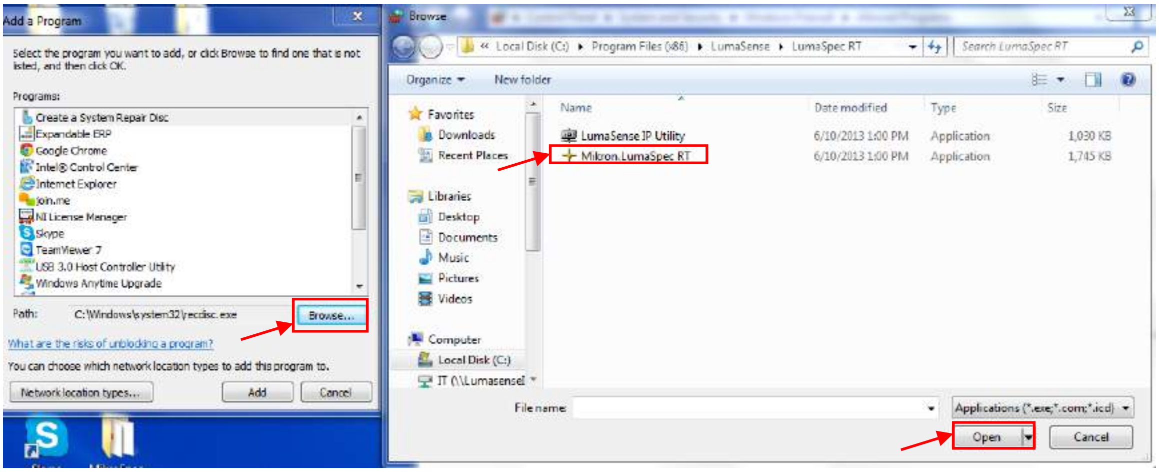
3. If LumaSpec R/T is not in the list, click **Allow another program…**



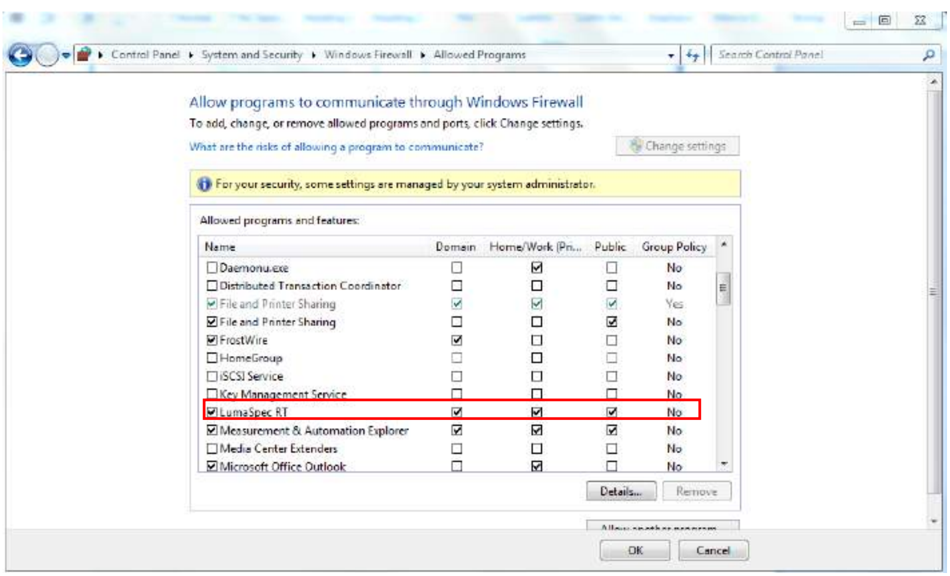
4. The **Add a Program** box will display. Click **Browse**… to navigate to the root directy of LumaSpec R/T. Typically you can find this directory at:

   C: \ Program Files (x86) \ LumaSense \ LumaSpec RT \ Mikron \ LumaSpec RT

   Select the file and click **Open.**



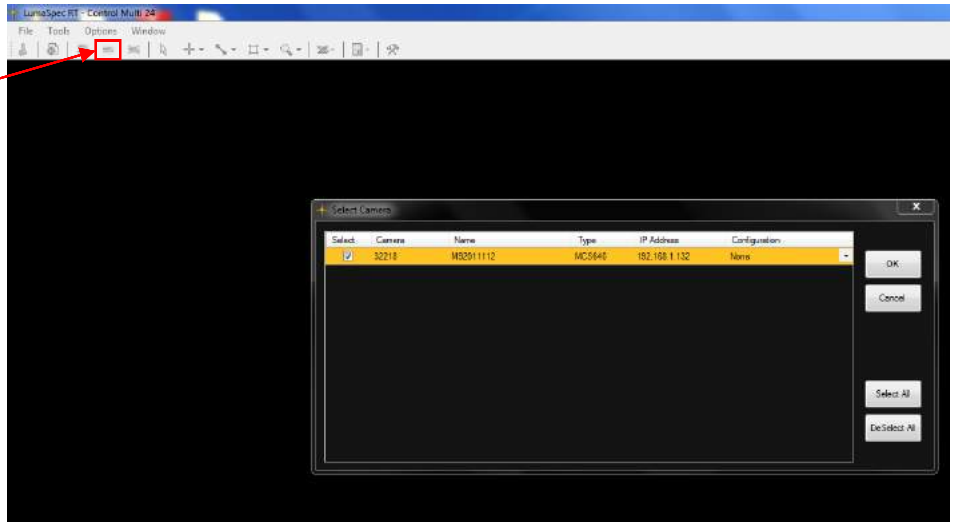
5. LumaSpec RT software should now appear in **Allowed Programs and Features.** Ensure the relevant networks are checked.



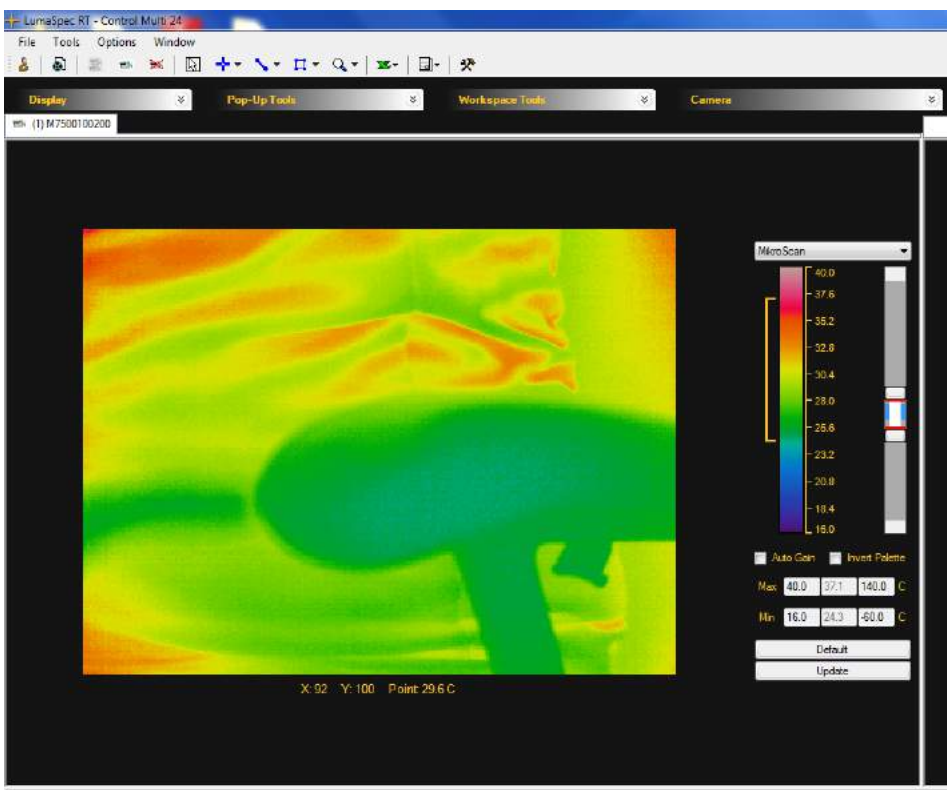
3.2.4 Acquire Images

1. Open the LumaSpec R/T software by double clicking on the desktop icon.
2. Click the **Discover** icon and the software will search for connected cameras. This may take a few seconds. A pop up window will display all of the discovered cameras.

Discover icon



3. Click **OK.**
4. The software will initialize and display the streaming camera video.



Refer to the software manual for additional controls or to learn more about the LumaSpec R/T software.

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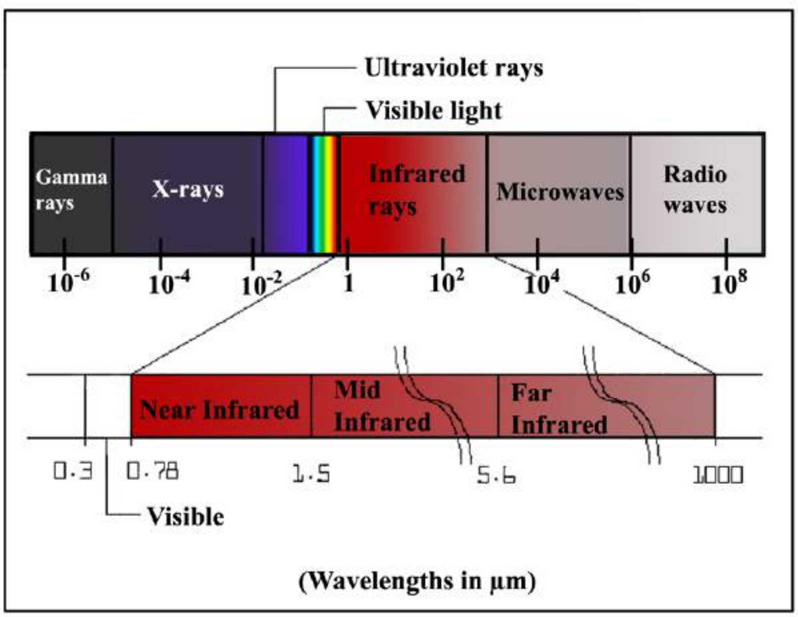
4 Principle of Thermal Imaging

All materials above 0 degrees Kelvin (-273 degrees C) emit infrared energy. The infrared energy emitted from the measured object is converted into an electrical signal by the imaging sensor in the camera and displayed on a monitor as a color or monochrome thermal image. The basic principle is explained in the following sections.

4.1 Infrared Radiation

The infrared ray is a form of electromagnetic radiation the same as radio waves, microwaves, ultraviolet rays, visible light, X-rays, and gamma rays. All these forms, which collectively make up the electromagnetic spectrum, are similar in that they emit energy in the form of electromagnetic waves traveling at the speed of light. The major difference between each 'band' in the spectrum is in their wavelength, which correlates to the amount of energy the waves carry. For example, while gamma rays have wavelengths millions of times smaller than those of visible light, radio waves have wavelengths that are billions of times longer than those of visible light.

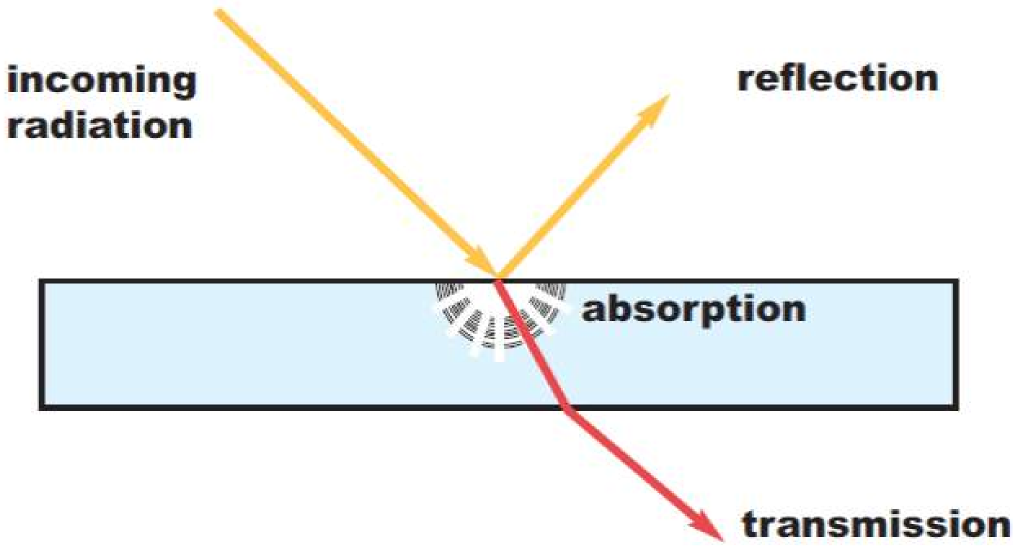


A Spectrum of Electromagnetic Radiation

The wavelength of the infrared radiation 'band' is 0.78 to 1000 µm (micrometers). This is longer than the wavelength of visible light yet shorter that radio waves. The wavelengths of infrared radiation are classified from the near infrared to the far infrared.

4.2 Emissivity

Infrared radiation is energy radiated by the motion of atoms and molecules on the surface of object, where the temperature of the object is more than absolute zero. The intensity of the emittance is a function of the temperature of the material. In other words, the higher the temperature, the greater the intensity of infrared energy that is emitted. As well as emitting infrared energy, materials also reflect infrared, absorb infrared and, in some cases, transmit infrared. When the temperature of the material equals that of its surroundings, the amount of thermal radiation absorbed by the object equals the amount emitted by the object.



Transmission, Absorption, and Reflection of Infrared Energy

The figure above shows the three modes by which the radiant energy striking an object may be dissipated. These modes of dissipation are:

a = absorption

t = transmission

r = reflection

The fractions of the total radiant energy, which are associated with each of the above modes of dissipation, are referred to as the absorptivity (a) transmissivity (t) and the reflectivity (r) of the body. According to the theory of conservation of energy, the extent to which materials reflect, absorb and transmit IR energy is known as the emissivity of the material.

4.3 Blackbody Radiation

The emissivity of a body is defined formally by the equation below as the ratio of the radiant energy emitted by the body to the radiation, which would be emitted by a blackbody at the same temperature.

Note: A blackbody is a theoretical surface, which absorbs and re-radiates all the IR energy it receives. It does not reflect or transmit any IR energy. Perfect blackbody surfaces do not exist in nature.

$$e = \frac{W_o}{W_{bb}}$$

Where,

W_o = total radiant energy emitted by a body at a given temperature T.

W_{bb} = total radiant energy emitted by a blackbody at the same temperature T.

If all energy falling on an object were absorbed (no transmission or reflection), the absorptivity would equal to 1. At a steady temperature, all the energy absorbed could be re-radiated (emitted) so that the emissivity of such a body would equal 1. Therefore in a blackbody,

absorptivity = emissivity = 1

Practical real life objects do not behave exactly as this ideal, but as described with transmissivity and reflectivity,

absorptivity + transmissivity + reflectivity = 1

Planck's Law

Energy radiated from the blackbody is described as follows ["Planck's Law".]

1)

$$W_\lambda = \frac{C_1}{\lambda^5 (e^{C_2/\lambda T} - 1)}$$

Stefan Bolzmann's equation

In order to obtain total radiant emittance of the blackbody, integrate the equation (1) through all wavelengths (0 to infinity). The result is as follows and is called "Stefan-Bolzmann equation."

2)

$$W = e\sigma T^4$$

Wien's displacement law

The temperature of blackbody can be obtained directly from the radiant energy of the blackbody by this equation. In order to find out the wavelength on the maximum spectral radiant emittance, differentiate Planck's law and take the value to 0.

3)

$$\lambda_m T = 2897.8 \mu m \cdot K$$

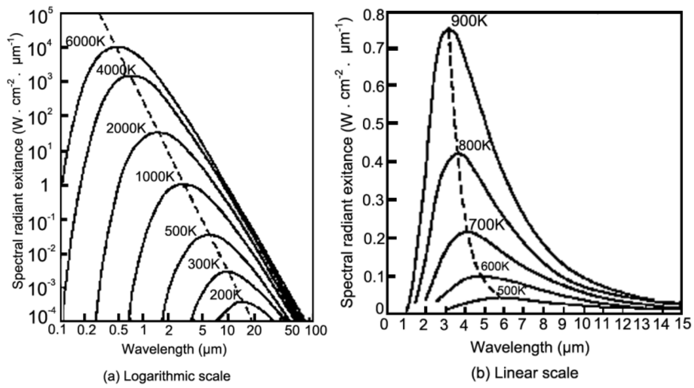
The equation is called "Wien's displacement law".

Where in (1) to (3),

$W\lambda$:	*Spectral radiant emittance per unit wavelength and unit area [W/cm^2 μm]*
λm :	*Wavelength of maximum spectral radiant emittance [μm]*
λ :	*Wavelength [μm]*
h :	*Planck's constant = 6.6261×10^{-34} [W · s^2]*
T :	*Absolute temperature [K]*
c :	*Light velocity = 2.9979×10^{10} [cm/s]*
K :	*Bolzmann constant = 1.3807×10^{-23}[W · s/K]*
s :	*Stefan-Bolzmann constant = 5.6705×10^{-12} [W/cm^2 · K^4]*
c1:	*Fist radiation constant = 3.7418×10^4 [/cm^2 · μm^4]*
c2:	*Second radiation constant = 1.4388×10^4 [μm · K]*

In radiation of a normal object, as the emissivity is (<1) times of the blackbody, multiply above equation by the emissivity. The following figures show the spectral radiant emittance of a blackbody.

(a) is shown by logarithmic scale and (b) is shown by linear scale.



Spectral radiant emittance of a blackbody

The graphs show that wavelength and spectral radiant emittance vary with the temperature. They also show that as the temperature rises, the peak of spectral radiant emittance is shifting to shorter wavelengths. This phenomenon is observable in the visible light region as an object at a low temperature appears red, and as the temperature increases, it changes to yellowish and then whitish color—thus shifting to shorter and shorter wavelengths as the temperature increases.

4.4 Blackbody Type Source and Emissivity

Although a blackbody is actually only a theoretical ideal, an object can be manufactured which approximates it. A law closely related to the blackbody is Kirchhoff's law that defines reflection, transmission, absorption and radiation.

a = e = 1

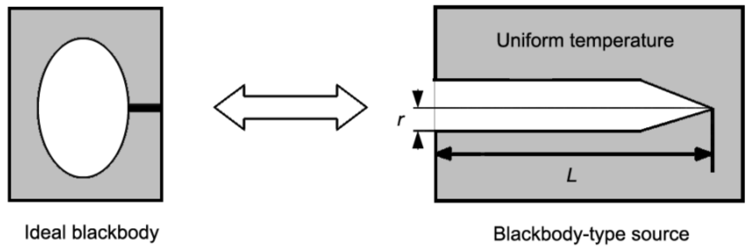
Key: a = absorptivity t = transmissivity r = reflectivity e = emissivity

Absorptivity equals emissivity, thus emissivity can be described by reflectivity and transmissivity.

e + t + r = 1

In order to obtain the true temperature of an object, it is necessary to obtain the emissivity correctly. Therefore, the emissivity of the object has to be measured by using a blackbody-type source which is closest to an ideal blackbody as possible. The blackbody-type source can be designed to meet the conditions pointed out by Kirchoff where "the radiation within an isothermal enclosure is blackbody radiation."

As a blackbody-type source for a measurement must radiate outside of the enclosed surface, a small hole is cut through the wall of the enclosure small enough not to disturb the blackbody condition. The radiation leaving this hole should closely approximate that of a blackbody. When the diameter of the hole is as 2r and the depth is as L, if L/r is equal or more than 6, it is used as a blackbody-type source for practical use. The following figure shows an example of a blackbody-type source based on blackbody conditions.



(The larger L/r ratio closer to a blackbody)

4.5 Determining Emissivity

Emissivity is the ratio of energy radiated from an object to the energy radiated from a blackbody. The emissivity varies with the surface condition of the object and also with temperature and wavelength. If this value is not accurate, then the true temperature cannot be measured. In other words, a variation or change in emissivity will cause a change in the indications on a thermal imager.

To approach the true temperature therefore,

> The emissivity must approximate 1.0 (➔ The measured object must be nearly a blackbody).
>
> The emissivity must be corrected (➔ The emissivity of the measured object must be internally corrected to 1 by the thermal imager).

Therefore, in order to perform correct measurement for true temperature, the emissivity is determined as follows:

1. By means of a printed table

   Various books and literature carry physical constants tables, but if the measuring condition is not identical, the constants may not usable. In such cases the literature should be used only for reference.

2. Determination by ratio — Option 1

   A contact-type thermometer is used to confirm that the measured object is in thermal equilibrium and that the blackbody-type source is at the same temperature. The object and the blackbody-type source are then measured with the radiation thermometer and the resulting energy ratio is then used to define the emissivity as follows:

   > EK : energy of blackbody-type source
   >
   > ES: energy of measured object
   >
   > X: emissivity of measured object

   Where, EK : ES = 1 : X

3. Determination by ratio — Option 2

   An object, resembling a blackbody, is attached to a heat source to make the temperature of the blackbody part and the measuring object the same. The ratio of infrared radiation energies are then determined as in #2 above.

4. Comparison with blackbody surface — Option 1

   A very small hole is made in the measured object to satisfy the aforementioned blackbody conditions, and to make the temperature of the entire object uniform. Then, using the emissivity correcting function of thermal imager, the emissivity is reduced until the temperature of the point to be measured equals the temperature of the small hole measured at an emissivity of 1. The emissivity setting should be the emissivity of the object. (This applies only when the conditions are the same as at measurement.)

5. Comparison with blackbody surface — Option 2

   If a small hole cannot be made in the object, then the emissivity can be obtained by applying black paint to the object and reaching a thermal equilibrium through similar procedures. But since the painted object will not provide a complete blackbody, the emissivity of the painted object needs to be set first and then the temperature can be measured. The following figure shows examples of blackbody paint.

Item Name	Emissivity	Measuring Wavelength
Heat-Resistant Paint (Black)	0.96	8 to 13μm
Heat-Resistant Paint (Black)	0.95	3 to 5.3μm
Niflon Tape	0.94	8 to 13μm

4.6 Background Noise

When measuring the temperature of an object by a radiation thermometer, it is important to take into consideration the above-mentioned emissivity correction as well as the environmental conditions where the measurements will be performed.

Infrared rays enter the thermal imager from the measuring object as well as all other objects nearby. Therefore, in order to avoid this influence, a function of environment reflection correction, etc. is required. Also, when accurate data is required, it is necessary to minimize the influence by shortening the transmission route of the infrared ray, for example.

Note: For low temperatures, masking tape or cornstarch can be used.

The following methods may be useful to reduce background noise.

1. Shorten the distance between the measured object and of the thermal imager. Please keep a safe distance to protect the operator as well as the instrument.
2. Have no high temperature object behind the measured object, such as the sun shining on the back of the measured object.
3. Do not allow direct sunlight to strike thermal imager.
4. Do not allow obstacles such as dust or vapor (which attenuates the infrared signal) between the measured object and the thermal imager.

4.7 Practical Measurement

There are a number of methods for correcting emissivity in order to obtain the true temperature. The correction procedure with each method will be explained next.

Note: If you already know the emissivity, you can make thermal imaging measurements immediately.

1. **Method of comparison or direct measurement with emissivity equal to approximately 1.0**

   1. Stabilize the temperature of the measured object or similar material.

   2. Open a very small hole (hereafter called blackbody part) in the object which the thermal imager must measure as to satisfy blackbody conditions.

   3. Then set the emissivity correcting function of thermal imager so that the temperature of the blackbody part and the measured surface will be the same. The obtained emissivity will be the emissivity of the measured surface.

   4. Thereafter when measuring the same type object, it is unnecessary to change the emissivity setting.

2. **Method of direct measurement of emissivity**

   If a hole cannot be made as in method 1, then apply black high emissivity paint and carry out the same procedures to obtain the emissivity. Since the black paint will not provide a perfect blackbody, first set the emissivity of the black paint and then measure the temperature.

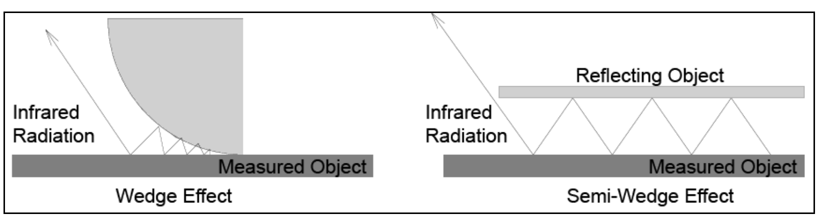
3. **Indirect measurement**

   Measure a sample similar to the measured object, and place it in a condition able to be heated by a heater, etc. Then measure the object and the sample alternately with the camera and when the indicated values are identical, measure the sample with a contact-type thermometer. Adjust the emissivity of the thermal imager to cause the temperature readout to match that of the contact measurement. The resulting emissivity is that of the sample.

4. **Measuring by Wedge effect**

   With this method, the emissivity of the measured surface itself is enhanced through use of the wedge or semi-wedge effect. But one must be careful about the number of reflections and/or the measuring angle.

   A small change in angle will reduce the emissivity enhancement.



Measuring by Wedge effect

4.8 Emissivity of Various Materials

From “Infrared Radiation, a Handbook for Applications” by Mikael A. Bramson

Material		Temperature °C	Emissivity ε
Aluminum	Polished	50 to 100	0.04 to 0.06
	Rough surface	20 to 50	0.06 to 0.07
	Strongly oxidized	50 to 500	0.20 to 0.3
	Aluminum bronze	20	0.6
	Aluminum oxide, pure, powder	Normal temperature	0.16
Brass	Dull, tarnished	20 to 350	0.22
	Oxidized at 600°C	200 to 600	0.59 to 0.61
	Polished	200	0.03
	Sheet, worked with emery	20	0.2
Bronze	Polished	50	0.1
	Porous, rough	50 to 150	0.55
Chromium	Polished	50	0.1
		500 to 1000	0.28 to 0.38
Copper	Commercial, burnished	20	0.07
	Electrolytic, carefully polished	80	0.018
	Electrolytic, powder	Normal temperature	0.76
	Molten	1100 to 1300	0.13 to 0.15
	Oxidized	50	0.6 to 0.7
	Oxidized to blackness	5	0.88
Iron	Covered with red rust	20	0.61 to 0.85
	Electrolytic, carefully polished	175 to 225	0.05 to 0.06
	Freshly worked with emery	20	0.24
	Oxidized	100	0.74
		125 to 525	0.78 to 0.82
	Hot rolled	20	0.77
		130	0.60
Lead	Gray, oxidized	20	0.28
	Oxidized at 200°	200	0.63
	Red, powder	100	0.93
	Lead sulfate, powder	Normal temperature	0.13 to 0.22
Mercury		0 to 100	0.09 to 0.12
Molybdenum		600 to 1000	0.08 to 0.13
	Filament	700 to 2500	0.10 to 0.30
Nichrome	Wire, clean	50	0.65
		500 to 1000	0.71 to 0.79
	Wire, oxidized	50 to 500	0.95 to 0.98
Nickel	Commercially pure, polished	100	0.045
		200 to 400	0.07 to 0.09
	Oxidized at 600°C	200 to 600	0.37 to 0.48
	Wire	200 to 1000	0.1 to 0.2
	Nickel oxide	500 to 650	0.52 to 0.59
		1000 to 1250	0.75 to 0.86

Material		Temperature °C	Emissivity ε
Platinum		1000 to 1500	0.14 to 0.18
	Pure, polished	200 to 600	0.05 to 0.10
	Ribbon	900 to 1100	0.12 to 0.17
	Wire	50 to 200	0.06 to 0.07
		500 to 1000	0.10 to 0.16
Silver	Pure, polished	200 to 600	0.02 to 0.03
Steel	Alloy (8% Ni , 18% Cr)	500	0.35
	Galvanized	20	0.28
	Oxidized	200 to 600	0.80
	Oxidized strongly	50	0.88
		500	0.98
	Rolled freshly	20	0.24
	Rough plane surface	50	0.95 to 0.98
	Rusty, red	20	0.69
	Sheet, ground	950 to 1100	0.55 to 0.61
	Sheet, nickel-plated	20	0.11
	Sheet, polished	750 to 1050	0.52 to 0.56
	Sheet, rolled	50	0.56
	Stainless, rolled	700	0.45
	Stainless, sandblasted	700	0.70
Cast iron	Casting	50	0.81
	Ingots	1000	0.95
	Liquid	1300	0.28
	Oxidized at 600°C	200 to 600	0.64 to 0.78
	Polished	200	0.21
Tin	Burnished	20 to 50	0.04 to 0.06
Titanium	Oxidized at 540°C	200	0.40
		500	0.50
		1000	0.60
	Polished	200	0.15
		500	0.20
		1000	0.36
Tungsten		200	0.05
		600 to 1000	0.1 to 0.16
	Filament	3300	0.39
Zinc	Oxidized at 400°C	400	0.11
	Oxidized surface	1000 to 1200	0.50 to 0.60
	Polished	200 to 300	0.04 to 0.05
	Sheet	50	0.20
Zirconium	Zirconium oxide, powder	Normal temperature	0.16 to 0.20
	Zirconium silicate, powder	do.	0.36 to 0.42

Material		Temperature °C	Emissivity ε
Asbestos	Board	20	0.96
	Paper	40 to 400	0.93 to 0.95
	Powder	Normal temperature	0.40 to 0.60
	Slate	20	0.96
Carbon	Filament	1000 to 1400	0.53
	Purified (0.9% ash)	100 to 600	0.81 to 0.79
Cement		Normal temperature	0.54
Charcoal	Powder		0.96
Clay	Fired	70	0.91
Cloth	Black	20	0.98
Ebonite		Normal temperature	0.89
Emery	Coarse	80	0.85
Lacquer	Bakelite	80	0.93
	Black, dull	40 to 100	0.96 to 0.98
	Black, shiny, sprayed on iron	20	0.87
	Heat-resistant	100	0.92
	White	40 to 100	0.8 to 0.95
Lampblack		20 to 400	0.95 to 0.97
	Applied to solid surface	50 to 1000	0.96
	With water glass	20 to 200	0.96
Paper	Black	Normal temperature	0.90
	Black, dull	Do.	0.94
	Green	Do.	0.85
	Red	Do.	0.76
	White	20	0.7 to 0.9
	Yellow	Normal temperature	0.72
Glass		20 to 100	0.94 to 0.91
		250 to 1000	0.87 to 0.72
		1100 to 1500	0.70 to 0.67
	Frosted	20	0.96
Gypsum		20	0.80 to 0.90
Ice	Covered with heavy frost	0	0.98
	Smooth	0	0.97
Lime		Normal temperature	0.30 to 0.40
Marble	Grayish, polished	20	0.93
Mica	Thick layer	Normal temperature	0.72
Porcelain	Glazed	20	0.92
	White, shiny	Normal temperature	0.70 to 0.75
Rubber	Hard	20	0.95
	Soft, gray, rough	20	0.86
Sand		Normal temperature	0.60
Shellac	Black, dull	75 to 150	0.91
	Black, shiny, applied on tin plate	20	0.82

Material		Temperature °C	Emissivity ε
Silica	Granular powder	Normal temperature	0.48
	Silicon (silica gel), powder	do.	0.30
Slag	Boiler	0 to 100	0.97 to 0.93
		200 to 500	0.89 to 0.78
		600 to 1200	0.76 to 0.70
Snow			0.80
Stucco	Rough, lime	10 to 90	0.91
Tar			0.79 to 0.84
	Tar paper	20	0.91 to 0.93
Water	Film on metal surface	20	0.98
	Layer > 0.1mm thick	0 to 100	0.95 to 0.98
Brick	Red, rough	20	0.88 to 0.93
	Fireproof clay	20	0.85
		1000	0.75
		1200	0.59
	Fireproof corundum	1000	0.46
	Refractory, strongly radiating	500 to 1000	0.80 to 0.90
	Refractory, weakly radiating	500 to 1000	0.65 to 0.75
	Silica (95% SiO2) brick	1230	0.66

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Index