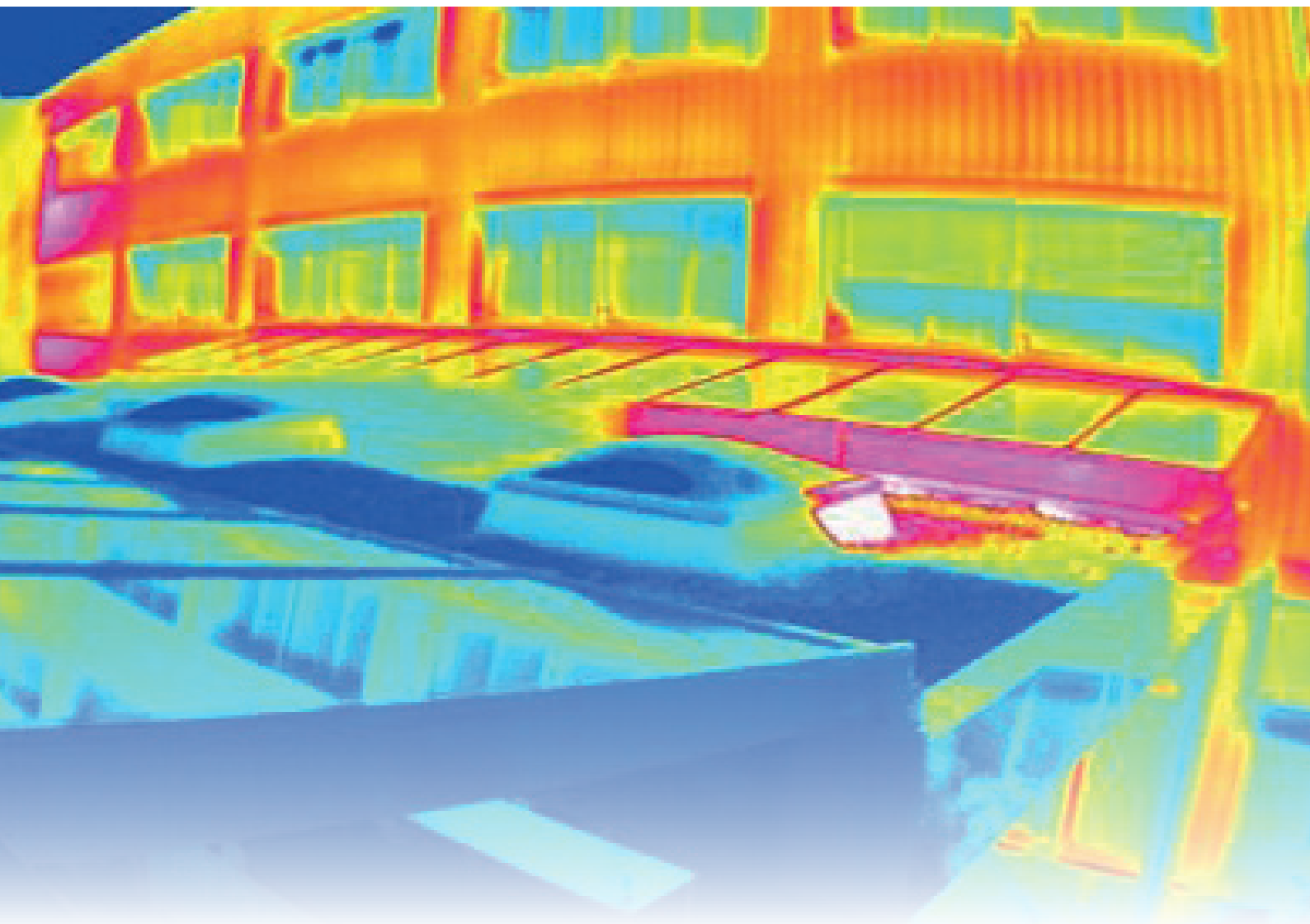


How Thermal Imaging Technology Works and its Benefits in Various Applications - Focus on Fire Protection, Quality Assurance and Security

White Paper

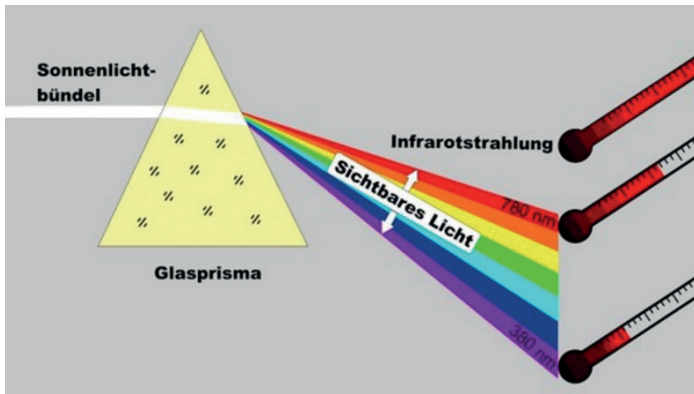


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1. Introduction

Thermal technology, the science of seeing beyond the visible, has become indispensable in numerous application areas. It makes our lives safer, better protected, and more efficient. In this white paper, you'll learn how thermal technology works, where it's being used, and how a once complex and expensive technology is now accessible and, most importantly, useful on many levels for any business or organization, large or small.



Let's start at the very beginning: In 1800, the German-British scientist William Herschel experimented with a prism that separated sunlight into its colors from violet, blue, green, and yellow to red.

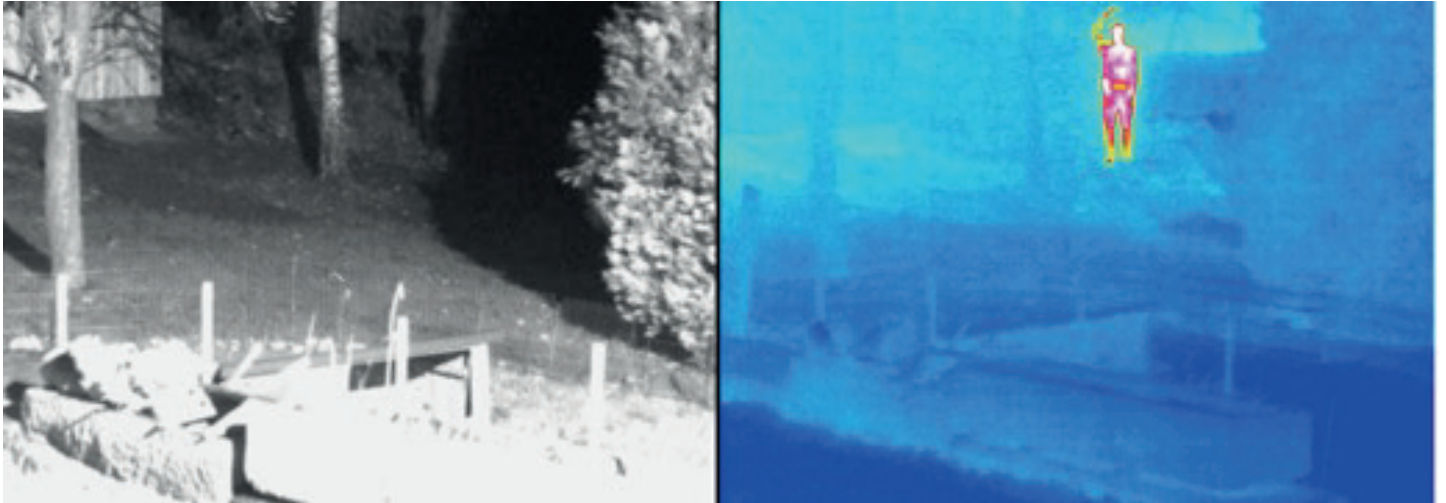
Herschel correctly concluded that there must be intense radiation beyond red light that is invisible to the human eye - and discovered infrared radiation. Herschel schloss korrekt, dass es intensive Strahlung auch jenseits des roten Lichts geben musste, die für das menschliche Auge unsichtbar ist – die Infrarotstrahlung war entdeckt.

At the time, he had no idea how his discovery would change our lives with innovative prevention and protection systems based on thermal imaging technology.

2. How does Thermal Technology work?

Thermal technology converts invisible temperature or heat radiation into visible images. A camera with thermal imaging technology takes a simple outline image of a location or object and overlays the site's or object's heat signature using infrared. A processor in the camera converts the infrared data into a color-coded image - for

example, red for hot, blue for cold, etc. This makes the image you see easily visible to the observer. For example, you can detect a person hiding in the undergrowth by their body heat.



You may also be familiar with thermal images in connection with the energy industry. Here, the technology is used to detect the sealing deficiencies of doors and windows on a house through different heat radiation.

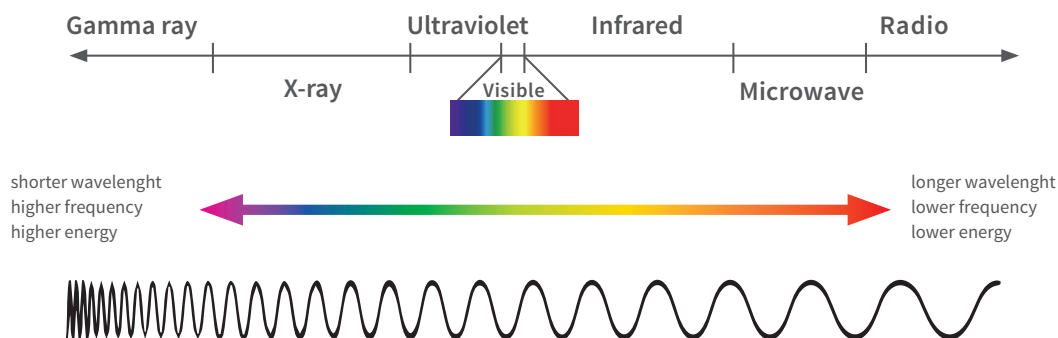


2.1. The surface is important

Thermal imaging technology makes the infrared heat radiation of the surface of objects or bodies visible without contact. Different materials react or radiate differently, which you must consider for correct measurement. An ideal measurement object is a black body with emissivity 1. Bodies with reflective surfaces, such as metals, have a lower emissivity (0.1 and lower). Human skin usually has an emissivity of 0.98.

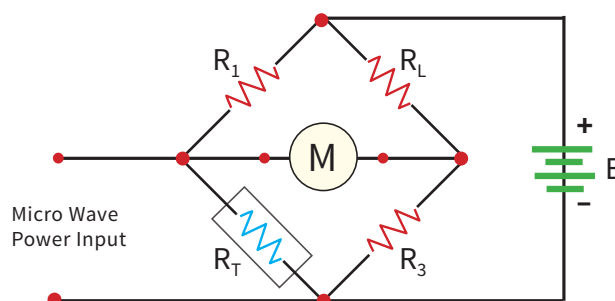
2.2. Electromagnetic radiation

Light and heat are based on the same phenomenon: electromagnetic radiation. The electromagnetic spectrum ranges from gamma rays with wavelengths smaller than atoms to radio waves that can be thousands of kilometers long. The human eye can perceive only a tiny fraction of this enormous range: light in the wavelength range of about 0.4 to 0.7 micrometers. Humans cannot see infrared radiation.



2.3. How to make Infrared or Thermal Radiation visible

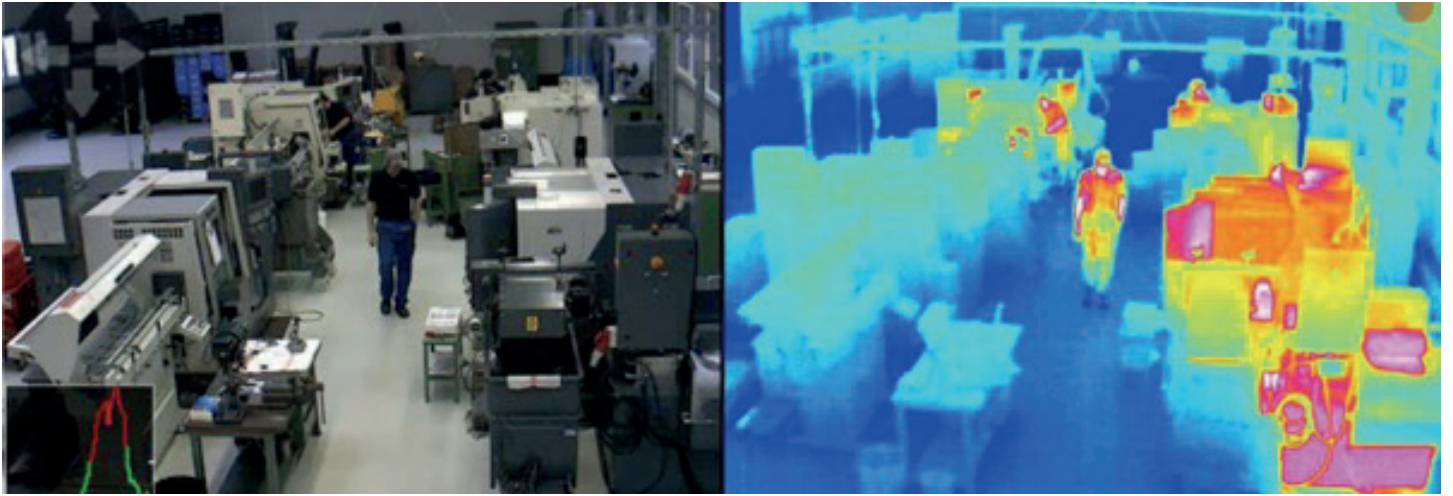
1878 was a decisive year in developing non-contact temperature measurement with the invention of the bolometric detector. The radiation sensor can measure the entire wavelength spectrum of electromagnetic waves. This is done by absorbing radiation and measuring the subsequent heating. The temperature-sensitive resistor absorbs the power of the measurand, generating heat in it. This heat causes the resistance of an element to change. The bridge circuit measures the change in resistance. The following figure shows the function of the bolometer.



Basic Bolometer Bridge Circuit

Regarding the number of pixels, the image resolution (bolometer matrix) is considerably lower than that of cameras for the visible spectral range. In contrast to cameras with optical image sensors, a

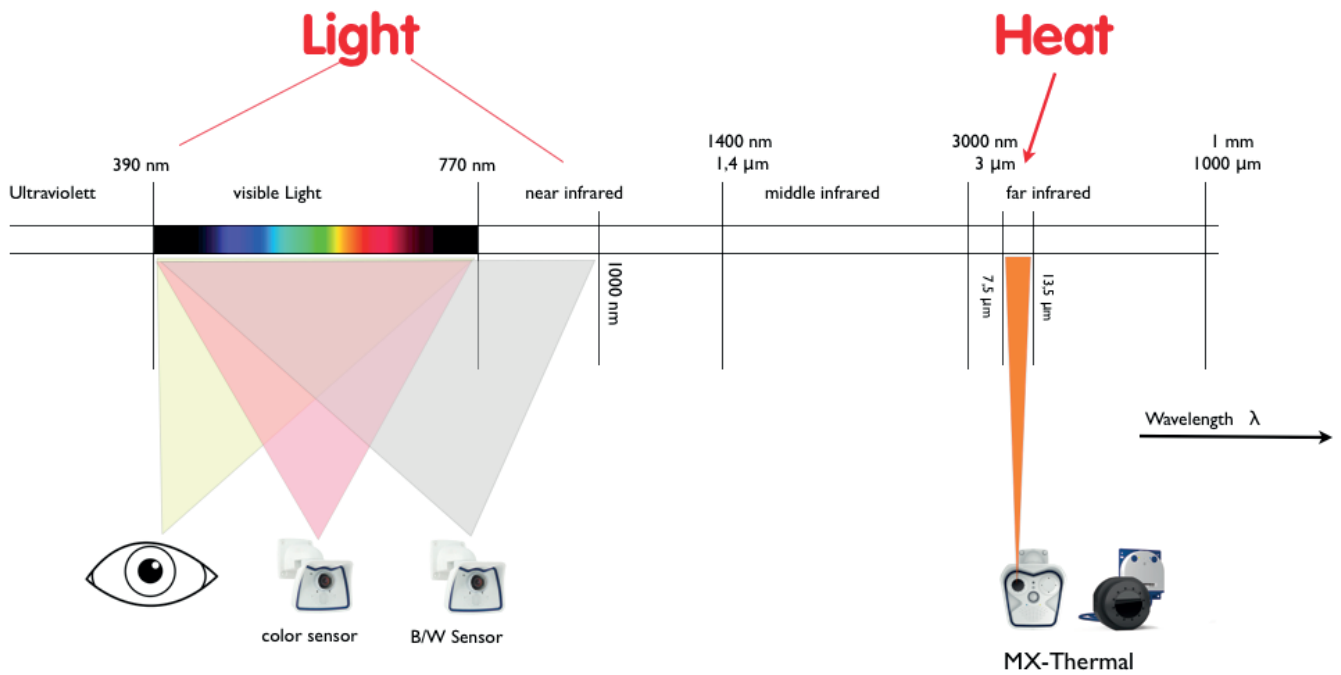
thermal imaging camera can detect minimal temperature differences and display them visually with colors.



MOBOTIX offers a range of thermal cameras that can automatically trigger temperature events within a temperature range of -40 °C to +550 °C. They detect infrared radiation in a wavelength of 7.5 to 13.5 nanometers (μ).

can still be resolved by the IR camera. MOBOTIX thermal imaging cameras can display temperature differences as small as 0.1 °C even from a greater distance and convert them into electrical signals that computers can efficiently process.

In addition to the optical resolution, the thermal sensitivity (Noise Equivalent Temperature Difference, NETD) is crucial for temperature measurement. It indicates how a small temperature difference



3. The Use and Benefits of Thermal Imaging Technology

Today, large and small companies and organizations from the public and private sectors use thermal technology as one of the most efficient and effective methods of protecting people, property, and assets. There are three core areas:

- ▶ Fire protection
- ▶ Quality control
- ▶ Safety

Thermal technology goes far beyond what optics and the human eye can see. Video thermal cameras can “see” day and night, in fog, smoke and bad weather, and detect critical incidents - such as early signs of fires, wear and tear, or camouflaged intruders - before they become major problems. That is what makes them so effective and valuable.

There are diverse applications where thermal technology proves to be an invaluable asset. Below, we highlight the three key application areas.

3.1. Fire protection and early fire detection

One area where thermal technology exemplifies its unique capabilities is fire prevention and detection. The key benefit of thermal technology in reducing the risk of fire is its ability to detect the early signs of where a fire might occur long before the flames arise. Essentially, the technology can spot an area of unusually high temperature that could ignite and start a fire. All other systems and solutions, even the human eye, will only detect a threat when there is some physical sign like smoke or flames.



3.1.1. Differentiation and advantages compared to conventional fire detection systems

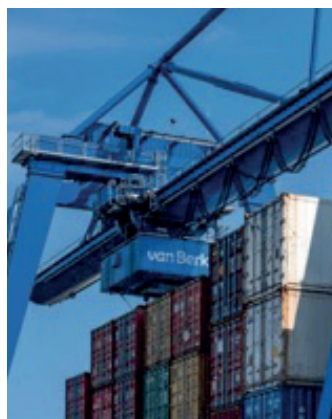
Every second is critical when it comes to protecting human life and property. Thermal systems often operate much faster and more reliably than conventional fire detectors. For example, line-type thermal sensors detect heat only after it has risen to the ceiling. Smoke detectors, as the name implies, rely on smoke development. And flame detectors only trigger when flames are visible.

On the other hand, thermal technology can detect heat and temperature changes before flames or smoke develop. It detects heat immediately, without contact and reliably, even from a distance. Thermal technology is also quick and inexpensive to install (easier than linear heat detectors, for example).

3.1.2. Opening up new areas for fire protection

Thermal imaging technology opens up new fields of application that could not be covered at all or only inadequately in fire protection because alternative systems cannot be installed there. After all, there is no ceiling and smoke is quickly blown away outdoors. In large rooms with high ceilings, the distance from the source of the fire to the detector results in delayed triggering. Fire protection with thermal video systems responds immediately and without contact, even outdoors and from great distances.

Thermal technology extends reliable fire protection to areas such as large and obscure outdoor areas, large rooms and buildings (halls, high ceilings), material accumulations (e.g., bulk materials such as grain), and warehouses (e.g., with chemicals, wood, or paper).



3.1.3. Time is Money – Regulations, Insurances & Certificates

Just as important as fire detection is the rapid implementation of suitable measures such as automatic extinguishing systems or qualified alarming by fire detection systems. Only the harmonious interaction of all those involved, including the best system integration, enables successful fire prevention and prevents damage - which can quickly threaten the company's existence.

TOP 10 Costliest Large-Loss Fires, 2020 (1)

(\$ millions)

Rank	State	Month	Type of facility	Estimated loss
1	August	California	“Siege” wildfires (2)	\$4,200.0
2	July	California	Navy ship under repair	3,000.0
3	June	California	Online sales warehouse	300.0
4	August	Minnesota	Hotel under construction	80.0
5	February	Georgia	Apartements under construction	61.0
6	January	New Jersey	Apartements under construction	51.9
7	May	North Carolina	Manufacturing, special equipment	50.0
8	May	Ohio	Apartements under construction	26.1
9	July	Massachusetts	Cold storage warehouse	25.0
10	February	Alaska	Village school building	20.0

(1) Large-loss fires of \$20 million or more in 2020.

(2) Includes multiple wildfires.

Note: Loss data shown here may differ from figures shown elsewhere for the same event due to differences in the date of publication, the geographical area covered and other criteria used by organizations collecting the data.

Source: National Fire Protection Association www.nfpa.org

Some thermal video systems are certified by recognized fire protection experts. Such tests and certifications show how established and reliable the technology has become in fire protection. Among other things, certifications and standards authorize the integration of thermal cameras in fire alarm systems and ensures legal or building regulations are met. This also makes settlement with the insurance company easier in the event of damage. MOBOTIX thermal cameras

are certified, for example, by the German Association for Loss Prevention (VdS), the French National Center for Prevention and Protection (CNPP), and the Austrian Federal Fire Brigade Association (PBST). In addition, with EN 54-10 certification, they comply with the EU Construction Products Regulation.



Key benefits of fire protection:

- ▶ Detect fire before flames appear
- ▶ Identify and warn of potential hazards
- ▶ Initiate countermeasures in time
- ▶ Avoid personal injury
- ▶ Minimize physical damage
- ▶ Meet insurance requirements

3.2. Quality assurance

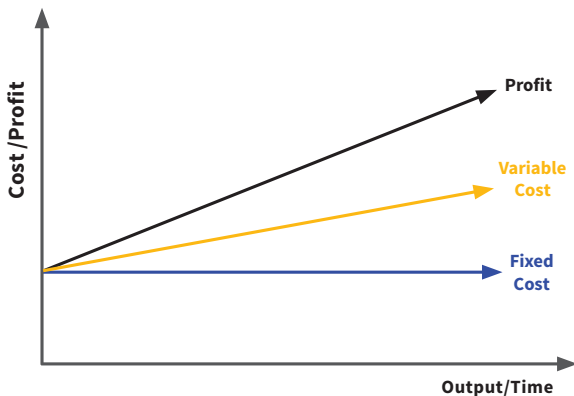
Improving and refining industrial operations and production processes is another ideal application for thermal technology. In particular, the technology is effective at making processes more efficient, less wasteful and less vulnerable to mistakes and breakdowns. Unplanned machine downtime is a major cost factor in the industry. Thermal imaging technology can contribute to:

- ▶ increase productivity
- ▶ reduce costs
- ▶ improve operational and product quality
- ▶ minimize energy consumption and CO2 emissions

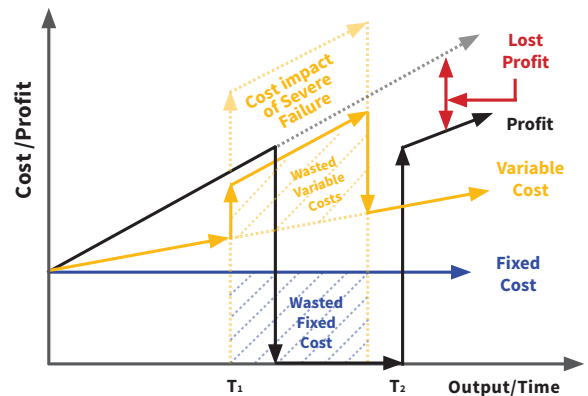
3.2.1. Preventive maintenance

Unplanned downtime is a burden on the earnings of the industrial sector. When machines or entire production lines come to a standstill, companies do not make money and earnings are reduced. For

large companies, this can quickly amount to 100,000 euros or more per hour.



(a)



(b)

The cost of downtime in relation to companies' sales proves that preventive maintenance has massive potential. Even if downtimes partly consist of planned shutdowns, it is mainly the unplanned shutdowns that cause trouble. In the automotive industry, the value of total downtime costs is a whopping 20% of sales, and in the heavy metal industry, 18% (source: ISA, International Society of Automation). Even a value of 4% compared to sales, as in the FMCG industry (food, consumer goods, etc.), offers the potential for valuable savings.

Using the example of the failure indications of a CNC milling machine, you can see that more than 20% of the downtime of this unit is due to unplanned machine failure.

Surveys show that predictive maintenance is already a strategic goal for two-thirds of automotive companies. After all, most companies already collect data to use and support predictive maintenance.

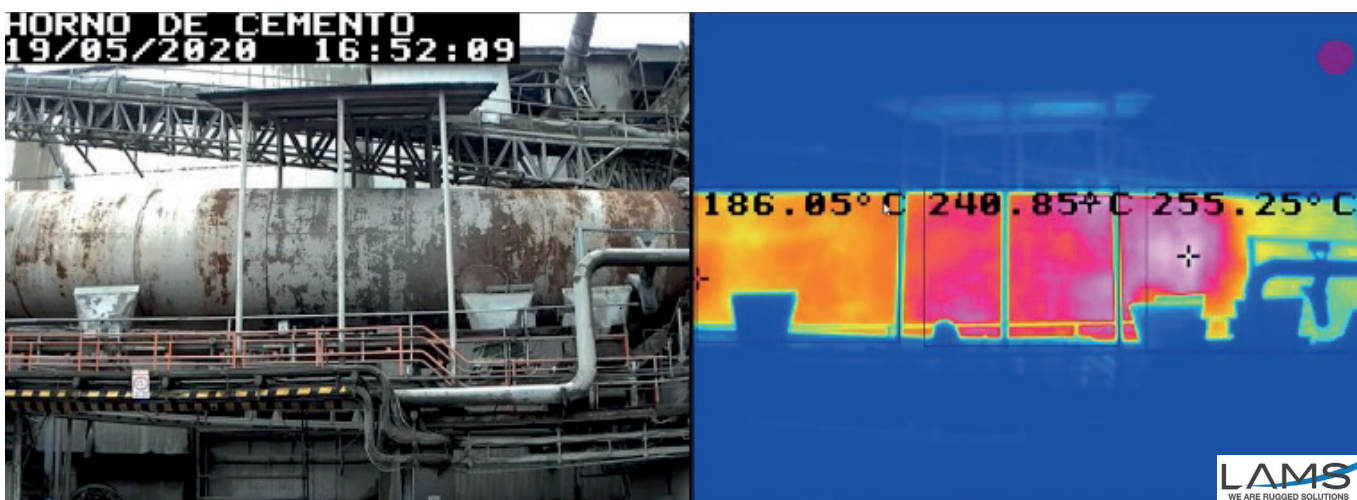
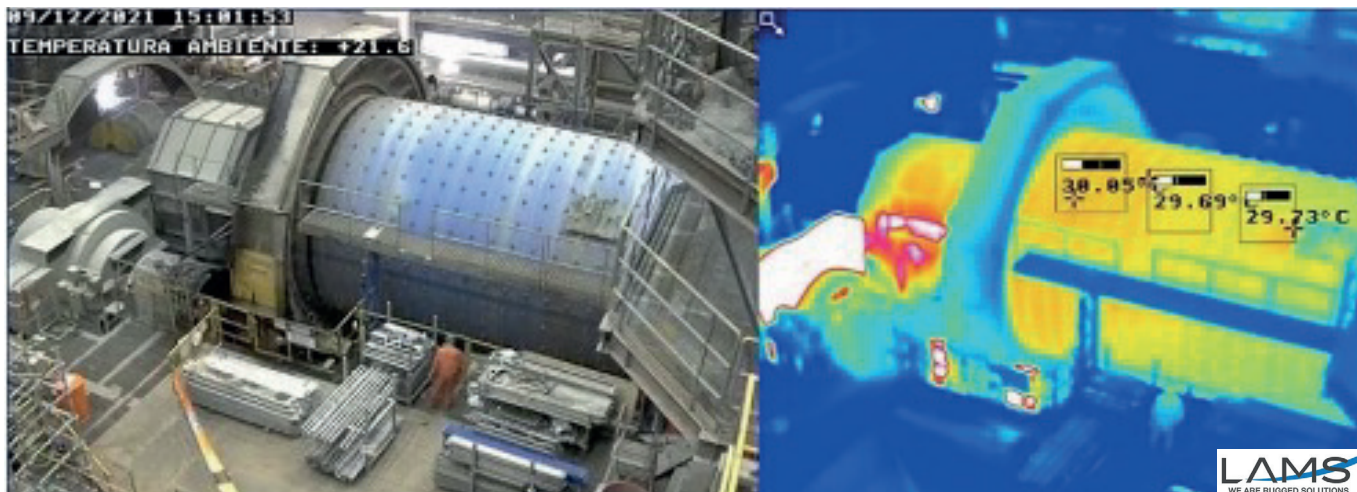
Beispiel: Ausfallzeiten einer CNC-Fräsmaschine

Month	Work time available (minute)	Delay of Machine						
		Cleaning time (minute)	Planned downtime (minute)	Warm up time (minute)	General breakdowns (minute)	Machine Break (minute)	Power cut-off (minute)	Total delay (minute)
March	30240	310	8505	292	605	2890	120	12722
Apr	30240	240	8505	288	651	2142	108	11934
Mei	28800	270	8100	275	744	1680	111	11180
June	31680	240	8910	312	715	1980	114	12271
July	23040	360	6480	312	560	1440	120	9272
August	31680	270	8910	332	733	1584	120	11949
Sept	30240	330	8505	275	639	1764	108	11621
Oct	30240	330	8505	280	717	1512	108	11452
Nov	31680	360	8910	292	823	2244	120	12749
Dec	28800	270	8100	292	605	1680	114	11061
Jan	30240	300	8505	300	602	1512	108	11327
Feb	28800	330	8100	292	608	1560	120	11010
Total	355680	3610	100035	3542	8002	21988	1371	138548

Annual Data Work Time and Delay Time of CNC Milling Machine

Thermal technology can detect wear and tear quickly and prevent machine downtime

MOBOTIX thermal technology reliably detects wear and tear, overload or damage through non-contact measurement - 24/7 while the system is running. Even procedures that are difficult or impossible to access can be effectively monitored in this way. The following images show cement mills whose wear (based on material density) is constantly detected using thermal technology.



3.2.2. Continuous Monitoring of Product Quality

In addition to avoiding machine failures, product quality is a central issue of quality assurance, which thermal video technology supports in production, processing or transport. Numerous production processes place special requirements on the temperature of raw materials, the intermediate, or the end product. Thermal technology enables targeted intervention when tolerance limits are exceeded

or undershot. Compliance with cold chains during storage or transport can also be necessary for product quality. Thermal cameras automatically detect and report critical temperature deviations of any kind - whether hot, warm, or cold. And that pays off, as the following case study from the foundry industry proves.

Case Study: How video saves foundry business 720,000€ a year

One company that is using video technology to enhance operations is a global foundry business that produces a wide range of products for some of the world's leading automotive, technology and consumer product brands.

Objectives

- ▶ Digitize the production process and monitor integration of multiple types of IoT (Internet of Things) systems
- ▶ Adjust die casting process by analyzing temperature behavior
 - Contactless measurement helps to permanently monitor the temperature tolerance of the permanent die casting mold of 1%
 - Corresponds to average process temperature of 200°C - 300°C approx. 2-3°C
- ▶ Increase efficiency by monitoring temperature increases and decreases to enable precise adjustment of process duration
- ▶ Use historical observation of the temperature behavior before, during and after the process to inform and fine-tune future operations

Production Requirement

- ▶ High pressure aluminum castings for parts used in the automotive industry
- ▶ Produce around 40 tons of material using almost 100 separate machines located around the world

Video Technology Solution

- ▶ 24 MOBOTIX cameras with build-in thermal sensors that gather raw temperature data
- ▶ The cameras are integrated with an event stream processing (ESP) application developed in-house
- ▶ The ESP application manages and processes the stream of 'event' data (in this instance continuous temperature readings)

MOBOTIX Proposition

MOBOTIX was used by the foundry because of its high-quality and reliable thermal imaging technology. As well as the cameras, MOBOTIX was able to provide software that integrated seamlessly with the ESP system. Also, there was no other comparable solution available.

Benefits

- ✓ Saves 720,000€ a year by reducing material waste in the casting process
- ✓ Increases operational efficiency and productivity
- ✓ Provides a low-cost, automated way to monitor and control temperature
- ✓ Data used to enhance and improve processes

The business carried out an analysis of material waste from defective die cast parts because of undetected temperature changes. It found that each machine was producing around 2,500€ worth of defective parts per month. By using the MOBOTIX thermal imaging solution, the business could identify temperature fluctuations and adjust them so that defects were minimized. With a total of 99 machines (currently 24 machines equipped) each saving 2,500€, this would equal an annual saving of 2.970.000 € !

3.2.3. Thermal technology as part of the smart factory

Manufacturing and processing operations are merging with information technology whether in mechanical engineering, logistics, or services. Communication is taking place in an intelligent, smart way. The smart factory uses Industrie 4.0 technologies to optimize processes and increase efficiency. Digital technologies such as artificial intelligence (AI), machine learning (deep learning), and the Internet of Things (IoT) come into play to automate and optimize manufacturing. Intelligent video and thermal technology, such as that from MOBOTIX, is an essential part of this.

A key component of this intelligent digitization consists of collecting, processing, and analyzing data. The industry is sitting on an enormous production and process data library. You can connect the intelligent MOBOTIX thermal systems to industrial systems such as SCADA via interfaces (machine-to-machine communication). This integration allows central data to be consolidated and evaluated. And in case of doubt, this saves a lot of money or ensures better yields.

The main advantages of quality assurance:

- ▶ Product and quality assurance
- ▶ Process and temperature monitoring
- ▶ Recognition of wear limits
- ▶ Avoidance of consequential damage
- ▶ Reduce costs
- ▶ Increase yields
- ▶ Interfaces to industrial systems for data collection and analysis

3.3. Perimeter protection/object protection

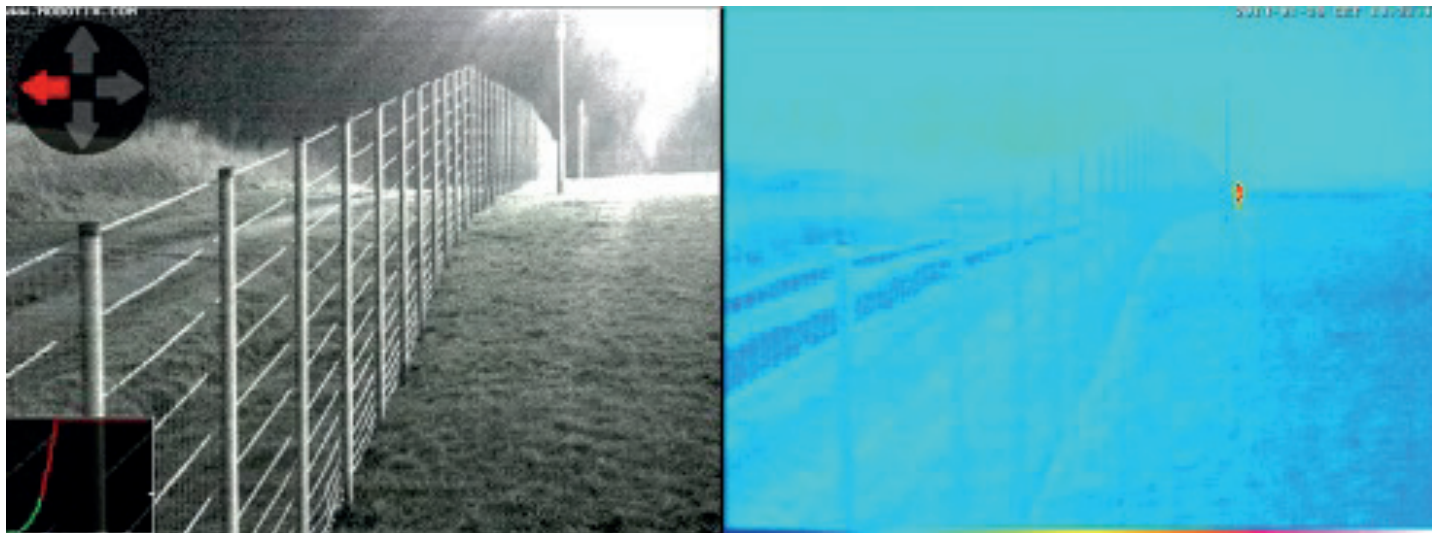
There is a need to reliably protect areas such as company premises or outdoor storage facilities and objects, public buildings, industrial plants, critical infrastructures, laboratories, and schools against uninvited intruders. And do that, in all weathers, every day and around the clock. In the private sector (residential burglaries), burglary crimes are split roughly 3:2 between day and night. The FBI reported 291,000 daytime burglaries in 2019 compared to 196,000 nighttime ones. The majority of burglaries occur in daylight because burglars assume residents are not home during the day.

In the commercial sector, however, surveillance in the dark or poor light plays a much more critical role. About 70% of burglaries and threats happen at night. This is because here it is the other way around, and the objects (e.g., production or offices) are not busy or very busy. Outside areas and warehouses are unclear in the dark. Incidentally, burglars are deterred by the very presence of an electronic device for burglary protection (study by the Dutch Ministry of Justice and FBI statistics).

3.3.1. Best view 24/7 also in poor visibility

While perimeter and property protection can be provided during the day using video security systems and intelligent analytics software, monitoring at night or in poor visibility poses particular challenges for the technology, especially since intruders and burglars operate in secret. Intelligent video thermal technology can provide reliable detection, even in total darkness.

People and the environment emit different temperatures. Thermal technology makes these visible, even in poor light and weather conditions. A thermal imaging system can detect suspicious persons, even in absolute darkness. Detection can also occur from distances of up to several hundred meters, over large areas, and in areas that are difficult to access.



An interesting sub-aspect of the object and perimeter protection with thermal cameras is cost-effective, energy-efficient monitoring. Since the technology does not require any illumination, thermal technology can save energy and money, especially with high energy costs.

Dual cameras (e.g., MOBOTIX M73 Thermal and S74 Thermal), which have a thermal image sensor and an optical sensor, allow you to superimpose the thermal image on the “real image” (thermal overlay).

Numbers, writing, signs, and other essential features are lost in the thermal image. A separate “optical real image” makes sense to localize the position and type of thermal event. This way, you can identify hotspots, such as dangerous heat sources. Immediate intervention becomes possible.



3.3.2. Data protection compliant monitoring (GDPR)

The protection of individuals and their privacy by laws and regulations such as the GDPR (Basic Data Protection Regulation) is given particular weight. Therefore, it is not readily permitted to use video surveillance in many public areas.



Thermal technology can also meet this need for protection. The generated thermal profile of thermal cameras does not show any details for personal identification and thus ensures privacy and compliance with GDPR. This also enables the monitoring of susceptible areas with great importance attached to data protection and personal rights. Thermal cameras are also used there during the day. Using dual camera systems enables automatic switching from thermal to optical sensor- only during an event - to obtain a high-resolution video sequence that can contribute to the conviction of unauthorized intruders. In combination with a white light emitter, the optical module can provide high-resolution “real images” even in darkness and contribute to accurate identification of intruders.

The main advantages of object and primet protection with thermal cameras:

- ▶ Best view day and night
- ▶ Detect intruders even in poor visibility
- ▶ Easy localization through thermal overlay (dual cameras)
- ▶ Enable data protection compliant monitoring

4. Case studies - thermal technology in action

Below are some examples of how thermal technology is improving lives, ensuring the safety of people and property, and improving operations.

Case Study 1:

MOBOTIX Customer: Kuhn Rikon, Switzerland

Sector: Industry - fire protection and process optimization

Kuhn Rikon is a world-renowned brand for pots and pans. There are complicated production steps in the manufacturing of the products. In 2015, one such step triggered a devastating accident with over 4.6 million euros in fire damage. Subsequently, an automatic fire extinguishing system was installed with the integration of MOBOTIX thermal cameras. The high-resolution video recording makes the production process inside the plant visible. If necessary, the camera automatically triggers three escalation levels: Heat warning on display, stop the machine, or turn off the system and automatically clear it. The system has been running smoothly since 2018. Thanks to the simplified control system, productivity has even increased by about 5%.



Case Study 2:

MOBOTIX Customer: ZAK – Zentrale Abfallwirtschaft
Kaiserslautern, Germany

Sector: Municipal waste management

MOBOTIX thermal imaging cameras integrated with a standard video system enable ZAK to monitor the temperature of stored timber. The video systems can automatically detect events within a range from -40 to 550 °C (-40 to 1022 °F) thanks to a thermal sensor technology and thermal radiometry. The technology operates as an automatic alarm when temperature thresholds are exceeded. A second camera is located where material is transported by crane so it can be fed into the incineration process. The thermal imaging technology shows ZAK exactly how high the temperature is in the timber shelter so it can take countermeasures if necessary.



Case Study 3:

MOBOTIX Customer: Your Homes Newcastle, UK

Sector: Public housing

Following the Grenfell Tower tragedy in 2017 when a fire killed over 70 people in the London tower block, housing organizations like Your Homes Newcastle are investing in early detection systems. As a pilot project, YHN has installed MOBOTIX thermal cameras in bin chute rooms in three multi-story blocks. The thermal technology continuously monitors temperature, triggering an alarm if an unexpected heat pattern is detected. Operators can assess and monitor the situation and alert fire services instantly. The cameras have been integrated into the existing infrastructure with no disruption to residents.



Case Study 4:

MOBOTIX Customer: London Underground, UK
Sector: Public transport system

London Underground has located several spare-part and equipment depots at convenient points around its railway network. The depots often house expensive and specialist equipment and parts which can take weeks to replace. But because the depots are in remote and exposed positions, they are vulnerable to theft. London Underground has installed MOBOTIX thermal cameras at the depots for 24-hour surveillance. The solution has reduced the number of cameras at each site, removed the need for perimeter lighting and helped to reduce costs.



Case Study 5:

MOBOTIX Customer: Entega AG
Sector: Energy, critical infrastructure - perimeter protection

Entega is a leading energy and infrastructure service provider and one of Germany's largest suppliers of green electricity and climate-neutral natural gas. The Entega site is home to the Entega AG headquarters, administrative buildings of subsidiaries, and industrial areas such as the gas turbine plant. Entega wants to protect this critical infrastructure from unauthorized persons (perimeter protection). The large outdoor area is secured even in absolute darkness thanks to thermal technology without additional lighting (perimeter protection). As soon as an object moves into one of the relevant monitoring areas, high-resolution optical sensors come into play. With the thermal overlay function, the thermal image can be superimposed on the visual image (color or black and white), allowing easy localization of the object (e.g., an intruder).



5. Thermal technology and MOBOTIX

MOBOTIX offers a comprehensive range of thermal technology solutions based on reliable, high-quality and 'German-made' hardware and software. In many fields of application, dirt and dust cannot be avoided. Coarse machines, bulk materials, and crushed or shredded materials provide corresponding loads. Dirt and dust occur naturally in large halls or open spaces.

When used outdoors, video systems are exposed to all weather conditions. They must be resistant to moisture, cold, and heat. High-end cameras, such as MOBOTIX video systems, are made for ambient temperatures from -40 to +65 degrees. The IP66 and IK07 protection classes ensure the best resistance to external influences (moisture and impact). Moreover, such video systems can be equipped with special vandalism or special housings, which make them ready for use in numerous applications, even in the most demanding environments.



For more detailed information about MOBOTIX thermal imaging solutions, please visit www.mobotix.com/en/thermal-technology



Sources

AFP Australian Federal Police, Boston University School of Public Health, Circuit Globe, CTIF World Fire Statistics, DIN Deutsches Institut für Normung, DLR Deutsches Zentrum für Luft- und Raumfahrt, Fireandemergency.nz, Flir, Forbes.com, Gov.uk, Insurance Information Institute New York, ISA International Society of Automation, NFPA.org National Fire Protection Association, Niederländisches Justizministerium, Spektrum.de, Technischwissenschaftlicher Beirat (TWB) der Vereinigung zur Förderung des Deutschen Brandschutzes e.V., Research Gate, Statista, UK Government Reports 2018/19, US Department of Justice, Wirtschaftsförderung Bremen GmbH