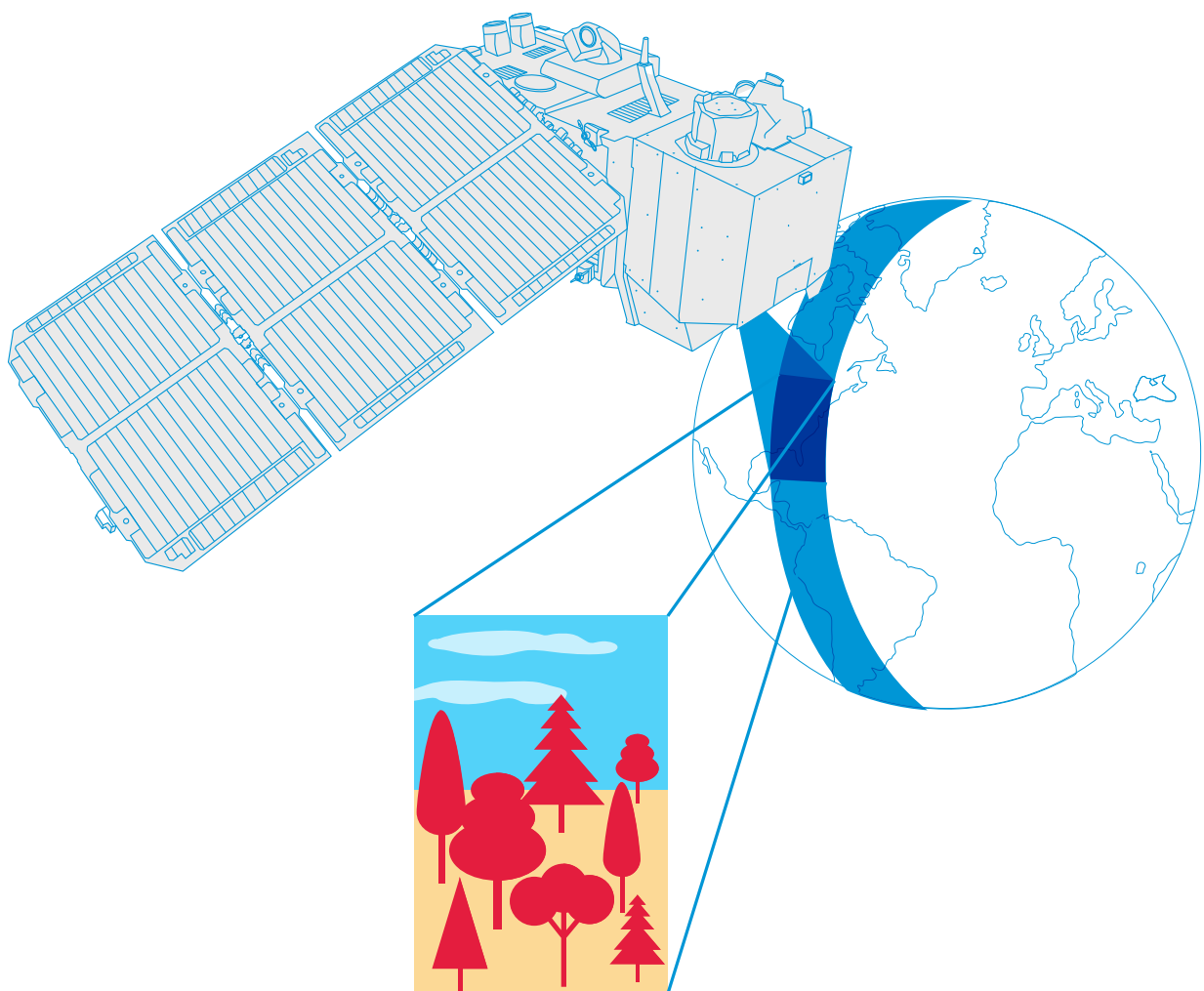
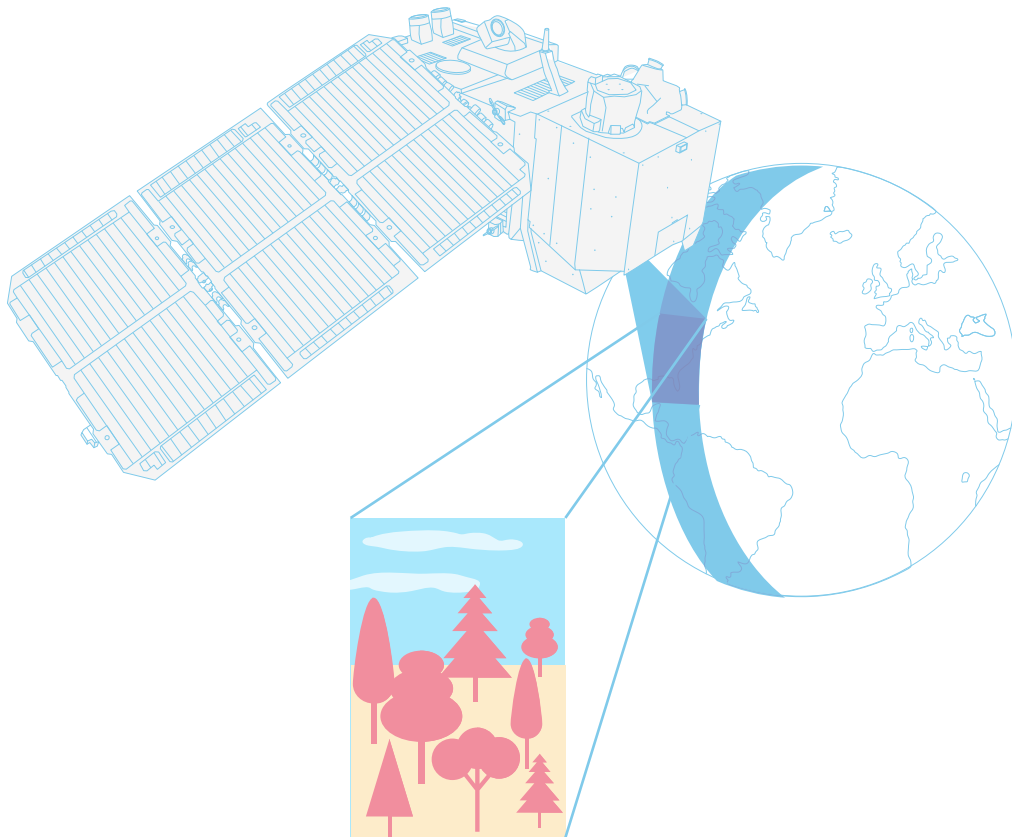


teach with space

→ INFRARED WEBCAM HACK

Using infrared light to observe the world in a new way





Teacher guide

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Activity concept developed for ESA by the National Space Academy (NSA), UK

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→ INFRARED WEBCAM HACK

Using infrared light to observe the world in a new way

Fast facts

Subject: Physics, Geography

Age range: 12-16 years old

Complexity: medium

Lesson time required: 30 minutes per activity

Cost: medium (10-30 euros per group)

Location: any indoor space with daylight

Includes the use of: webcam and computer

Keywords: Earth observation, Infrared light, Satellite imagery, Physics, Geography.

Brief description

This set of three activities will enable students to understand the electromagnetic spectrum and observe infrared radiation through the modification of a cheap webcam. It will enable discussion of how infrared radiation can be used to obtain information that is not available using visible light. Students will also analyse satellite images providing them with a context to understand why it is useful to “see” in infrared.

Learning objectives

- Identify the different types of electromagnetic radiation.
- Describe different applications of infrared light.
- Use tools available on the internet to collect and analyse satellite data.
- Understand how infrared light can be used to monitor the health of vegetation.
- Identify false colour and true colour satellite images.

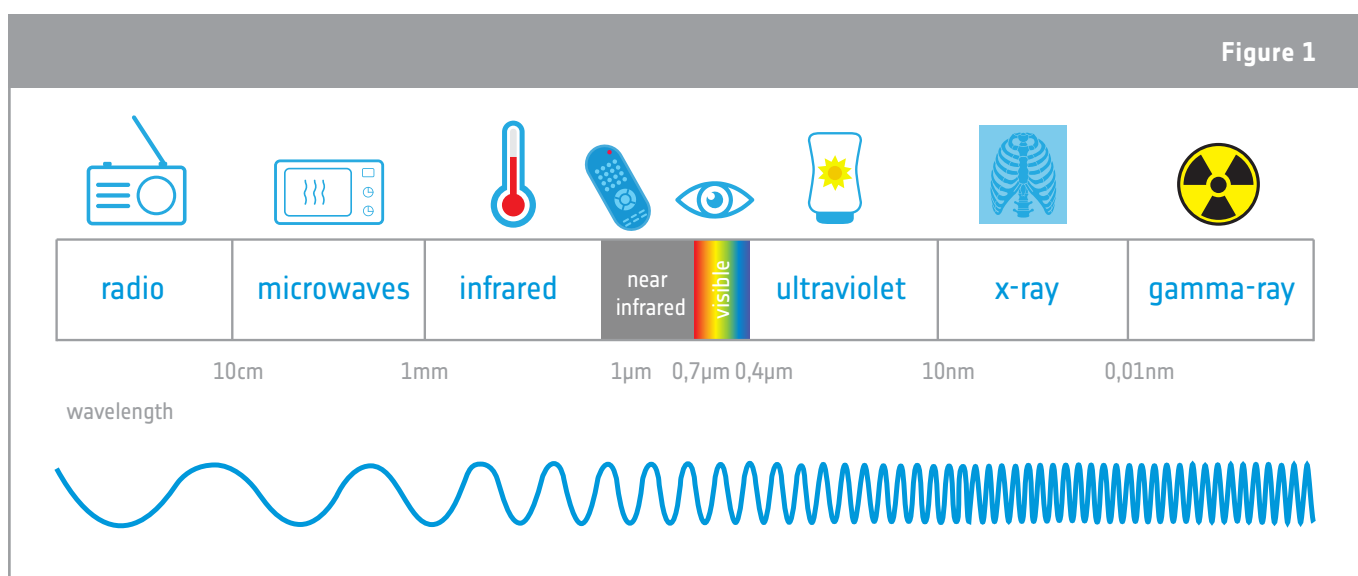
→ Summary of activities

Summary of activities					
	Title	Description	Outcome	Requirements	Time
1	Hacking the webcam	To modify a webcam so that it sees in near-infrared light rather than in visible light.	An Infrared webcam	None	30 minutes
2	Looking at objects with an infrared camera	To look at different types of objects, observing each in both visible and near-infrared light.	To identify different applications of infrared light and understand how infrared light can be used to find out information that is not available using visible light.	Completion of Activity 1	30 minutes
3	Looking at the Earth in infrared light	To analyse true colour satellite images and compare them to false colour images that visualise near-infrared light.	To understand how infrared light can be used to monitor the health of vegetation and why it is useful to “see” in infrared.	None	30 minutes

→ Introduction

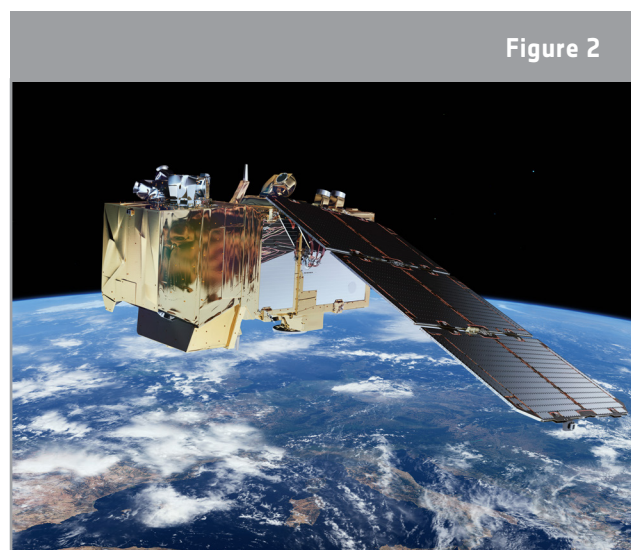
The electromagnetic spectrum categorises the electromagnetic radiation that exists, including infrared radiation (Figure 1). Most electromagnetic radiation emitted by the Sun is reflected or absorbed by Earth's atmosphere. However, some radiation like visible radiation, radio waves, and part of infrared can pass through the atmosphere.

Objects with different surface features reflect and absorb the Sun's radiation in different ways. The reflected radiation contains information about the surface of the object, and enables us to see the colour and form of the object. The human eye can only see a very limited range of the spectrum, the visible light. However we can use different instruments to see what is invisible to us. Earth observation satellites, for example, carry scientific instruments that can see in the visible and the infrared range, as well as other ranges of the electromagnetic spectrum.



↑ The electromagnetic spectrum categorises different types of radiation, from the longest (radio) to the shortest (gamma ray) wavelengths.

In this resource, we will focus on the near-infrared and visible parts of the spectrum. Infrared radiation is divided into different parts, just like visible light is divided into different colours. Near-infrared radiation, with its slightly longer wavelengths than visible light, is reflected by vegetation, delivering detailed information about plants on Earth. That is why this part of the electromagnetic spectrum is used in Earth observation satellites to monitor Earth's vegetation.



↑ The European Sentinel-2 satellite carries an high-resolution multispectral imager with 13 spectral bands for a new perspective of our land and vegetation.

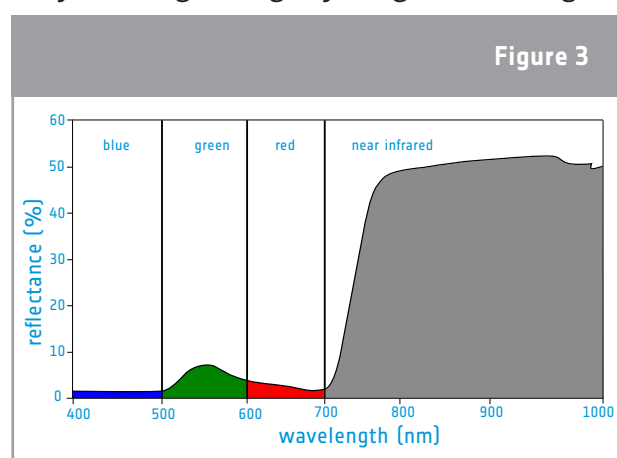
→ Background

Vegetation monitoring

Plants have a particular way of reflecting electromagnetic radiation. The chlorophyll in the plants absorbs light to get energy for the photosynthesis process. But only the red and blue part of the visible light are needed. The green light is reflected, which explains why leaves appear green to us. The near-infrared light is not needed for the photosynthesis, therefore most of the light is reflected by the cell structure of the leaf.

Figure 3 shows the percentage of reflected radiation, also called reflectance, for a healthy plant. The blue light is absorbed almost completely by the chlorophyll, about 10% of the green light is reflected, and the red light is absorbed almost completely. Moving to slightly longer wavelengths, about 50% of the near-infrared light is reflected. The combination of low visible reflectance and high near-infrared reflectance is a characteristic of most plant types.

When a plant becomes less healthy, for example due to water scarcity, it reflects more of the visible red light and less of the near-infrared light. This can also be seen in autumn when leaves turn yellow and red, due to phenology. The bigger the difference between the reflected red and near-infrared light, the healthier a plant is. This fact is used in Earth observation to calculate indices which help us obtain information about the health of plants on a large scale.



↑ Percentage of radiation reflected by a healthy plant for the wavelengths of visible light and near-infrared light.

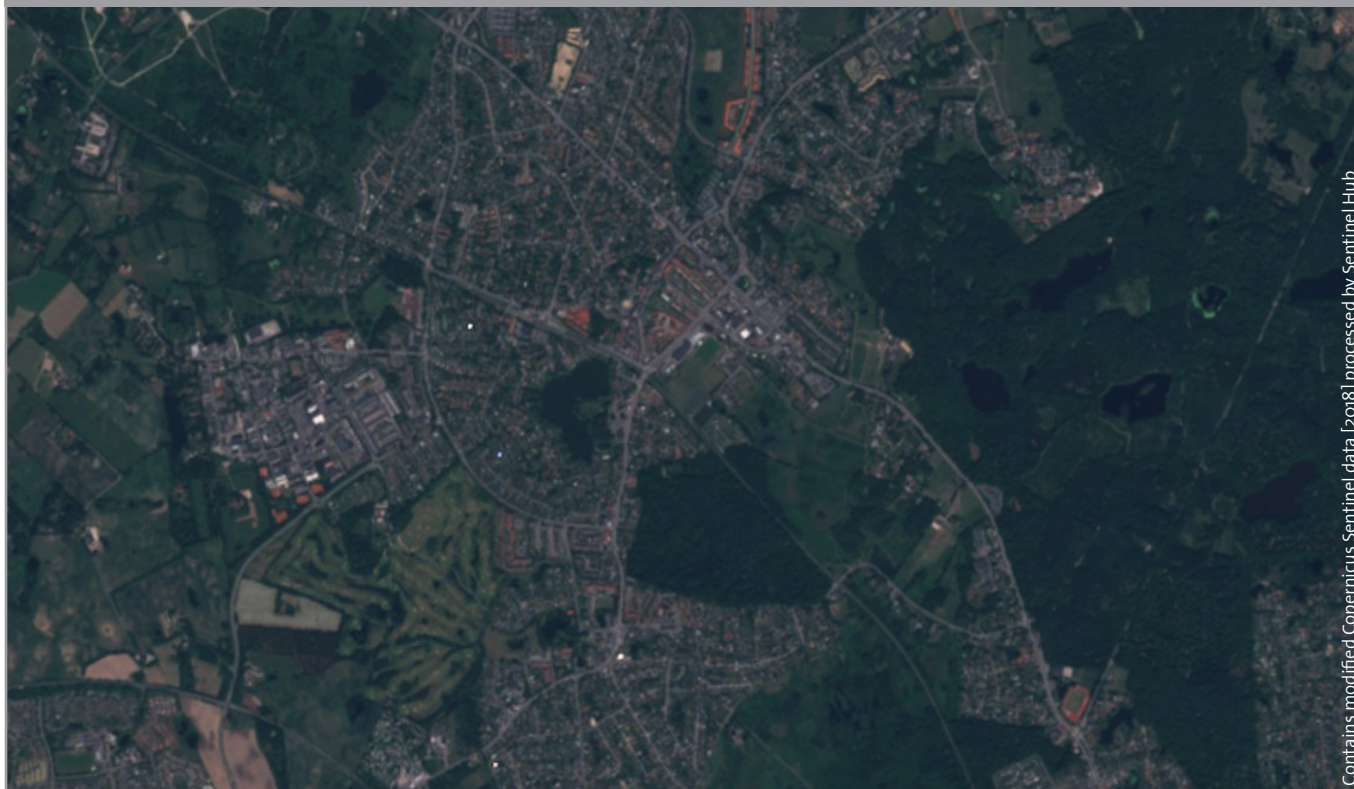
True colour and false colour images

A way to visualise reflected near-infrared light is to create false colour images, making use of the fact that cameras carried by satellites can 'see' more than just the visible part of light. A false colour image uses at least one wavelength outside the visible range, and as a result the colours in the final image may not be what we expect them to be. For example, grass is not always green! A true colour image combines actual measurements of reflected red, green, and blue light. The result looks like the world as we are used to seeing it.

In the figures below, we can see a true colour image (Figure 4) and a false colour image (Figure 5) of the town of Birkerød in Denmark. The false colour image shows reflected near-infrared light as red, red light as green, and green light as blue. Since plants reflect more near-infrared than green, vegetation areas will appear red. The brighter and richer red indicates a higher reflectance in the near-infrared, therefore indicating more and healthier vegetation. In the true colour image, the vegetation appears green, like we are used to seeing it.

Overall, the reflectance in the visible light is much lower than the one in the near-infrared, and the image is darker. This makes it harder to identify water bodies in the real colour image, because the reflectance is also very low. In the false colour image, the water bodies can be clearly identified due to the high difference in reflectance for water and the surrounding vegetation (high reflectance). Water absorbs most of the incoming light—near-infrared, red, and green—and therefore has a very low reflectance.

Figure 4



↑ True colour image of the town of Birkerød in Denmark.

Figure 5



↑ False colour image of the town of Birkerød in Denmark.

→ Activity 1 – Hacking the webcam

In this activity, students will modify a webcam so that it sees in near-infrared light rather than in visible light.

Equipment (for each infrared camera)

- 1 webcam with manual focus ring on the front
- 1 drawing pin or a similar pin
- Two pieces of exposed photographic film or a polarising filter large enough to cover the lens
- Clear tape
- Scissors
- Computer

Exercise

Instructions for hacking the webcam are provided in the student activity sheet. Cheap webcams are usually easier to disassemble than more expensive models. The example used in the student activity sheet is a Trust 17405. Refer to the Infrared Webcam Hack video for a video guide of how to set up and carry out the experiment. Students can work in small groups. Alternatively, the webcams can be modified in advance, and students can run Activities 2 and 3. The principal modification to be performed is to remove the infrared filter. Depending on the conditions of light it may be necessary to add a visible light filter.

Filters work by blocking light within a specific wavelength range. Two polarised filters are required to block visible light. This is because the wave may be moving up and down, or side to side (this single-plane oscillation is called polarisation). Two filters ensure that all the visible radiation is blocked.

Most webcams are “plug and play” – the software required to run them is already on the camera. However, depending on the webcam you use, there is a small chance that it may be necessary to install the operating software before the webcam is plugged into a computer.

Teachers should make sure that students understand that the hacked camera is a near-infrared camera, not a thermal imaging camera!

The sensors used in digital cameras are sensitive to light with wavelengths up to around $1\ \mu\text{m}$ (near-infrared). Thermal imaging cameras use infrared at longer wavelengths. These cameras are sensitive to the infrared radiation which is emitted by all objects with a temperature above absolute zero and not visible to our eyes. The higher the temperature of an object, the shorter the wavelength of the emitted radiation will be. When the temperature of an object is high enough, the radiation emitted can be imaged using near-infrared cameras or our very own eyes. We can see this in our kitchen: when a toaster reaches very high temperatures, it turns red!



↑ Infrared webcam hack video. See links section.

→ Activity 2: Looking at objects with an infrared camera

In this activity, students will look at different types of objects, observing each in both visible with their eyes and near-infrared light with the modify webcam.

Equipment

- Infrared camera (from activity 1)
- Remote control
- Led light
- Candle
- Healthy plant and fake plastic plant

Exercise

Daylight is necessary for the experiment with the plants. The experiment should always be tested in the classroom before doing it with the students. Depending on the light conditions in the room it may be necessary to block the visible light and to put the polarising filter/exposed film in front of the lens.

Students should observe the different objects and fill the table in the student activity sheet, where they describe how they see each object in both types of light, and then give an interpretation for their observations.



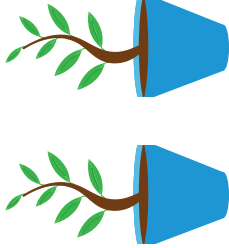
Results

See the table on the next page.

Discussion

The remote control, the candle and the LED light send out (emit) infrared radiation. With the help of the hacked webcam, students can 'see' infrared light, e.g. emitted from the remote control. Looking at light sources from daily life, like the LED light and the candle, the infrared camera allows us to investigate which one emits less infrared light and is therefore more energy-efficient.

Looking at the plants with the hacked webcam, what we see is reflected daylight. As the real plant reflects a lot of near infrared light and this is related to a healthy plant structure, we can understand how healthy a plant is when looking at it in infrared light.

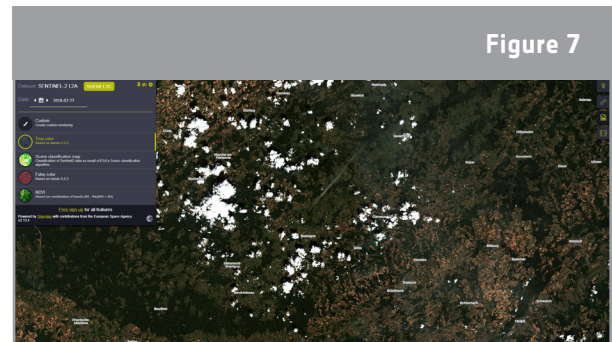
Objects	Describe your observations		Explain your observations
	Visible light	Infrared light	
Remote control 	<p>When pressing a button and looking at the infrared sender, nothing can be seen, (except sometimes a faint light when the wavelength used by the remote control is very close to the visible wavelengths).</p>	<p>Looking at the remote control through the webcam and pressing the buttons, a bright light signal from the infrared sender can be seen.</p> <p>Tip: This is also visible with the camera of some smartphones!</p>	<p>Remote controls are used to control from a distance some devices like televisions. How does the receiver (e.g. the television) know which button on the remote control has been pressed? Each button sends out on-off signals at a certain wavelengths of the infrared light. The pattern of the signal is related to one button on the remote. For this reason, we can see the signal emitted by the remote with the infrared camera.</p>
LED vs. candle 	<p>The LED light and the candle both emit light. The colours look different. The candle has a warmer light, whereas the LED light is whiter.</p>	<p>Looking through the webcam, the candle appears much brighter than the LED light.</p>	<p>The candle not only emits visible light but also heat which can be visible in the infrared, and for this reason the candle appears brighter with the infrared camera. The LED light does not emit a lot of light in the infrared like the candle, but it appears brighter in the visible.</p>
Living vs. fake plants 	<p>Both plants are green when looking at them.</p> <p>Tip: If there are any yellow or brown leaves, they can be compared to the healthy, green leaves.</p>	<p>Looking at both plants with the infrared webcam, the green leaves of the living plant appear much brighter than those of the fake plant.</p> <p>Yellow or brown leaves are much darker than the green leaves.</p>	<p>In visible light both plants look green and real. In the infrared camera the living plant looks much brighter than the fake one. The living plant reflects a lot of radiation in the infrared, as this part of the light is not needed for photosynthesis. High reflectance of infrared light is caused by the spongy mesophyll. This can be related to a healthy plant structure.</p> <p>The plant structure of the yellow or brown leaves is already destroyed, so the reflectance of the infrared light is much lower.</p>

→ Activity 3: Looking at the Earth in infrared light

In this activity students will analyse satellite images. The activity introduces true colour images and compares them to false colour images that visualise near-infrared radiation. It provides students with a context so that they understand why it is useful to “see” in near-infrared.

Exercise

The satellite images were downloaded from the EO Browser, an online application where you can access ready-to-use satellite images in true colour, false colour showing near-infrared, and many more products! You can explore this tool and start by showing the students their hometown in the summer and the winter with true and false colour images. Students can also research their own examples.



↑ Screenshot of the EO Browser online tool (08.08.2018).

1. **Observe the true colour image below taken by the Sentinel-2 satellite (Northern Germany, 28.11.2016). Which of the following features can you identify?**
 - ☐ Agriculture fields
 - ☐ Snow
 - ☐ Forest
 - ☐ Clouds
 - ☐ River
 - ☐ Lakes
 - ☐ Streets
 - ☐ Cars
 - ☐ Buildings
 - ☐ People

Teachers can ask students why there are no cars or people visible in the image. The reason is the spatial resolution of the satellite image. The spatial resolution is the area on Earth that is represented by one pixel of the satellite image. The satellite image in this exercise has a spatial resolution of 10m, therefore a pixel represents 10m x 10m on Earth. At this resolution, people and cars cannot be identified.

2. **Observe the false colour image.**
 - a. **Try to find the features you previously observed. Can you also identify new features?**

All features can be identified. Water bodies, especially the ones in the forest, can now be distinguished much more easily.

- b. **What surface type/feature appears red in the false colour image? Distinguish between bright red and dark red.**

Vegetation/plants appear red. The fields are bright red and the forest is dark red. The structure of the forest can be identified due to the shadow of the treetops.

3. Describe the differences and similarities between the true colour image in Exercise 1 and the false colour image in Exercise 2.

In the true colour image, the vegetation (grass and forest) appears in very dark green, and the bare soil in brown. Buildings and roads are grey. In the false colour images, the grass and forest appear in red.

Water bodies (lakes and rivers) are very dark in both images, and large buildings that could represent industrial areas are very bright/white in the true and false colour images.

4. Discuss the advantages and disadvantages of the true colour and false colour images showing near-infrared light.

Overall the reflectance displayed in the true colour image is much lower than the one in the false colour image, and the image is darker. This makes it harder to identify water bodies in the real colour image, because the reflectance is also very low. In the false colour image, the water bodies can be clearly identified due to the difference in reflectance values for water (very low reflectance) and the surrounding vegetation (high reflectance).

In the false colour images, more details of the vegetation can be identified. The reason is the high reflectance in combination with the shadows that occur due to the structure of the treetops. The angle of incidence of the Sun has to be taken into account when discussing shadows: the image was taken in November, meaning that the angle of incidence is lower than in the summer, therefore the shadows are bigger and rough surfaces appear darker.

→ General discussion

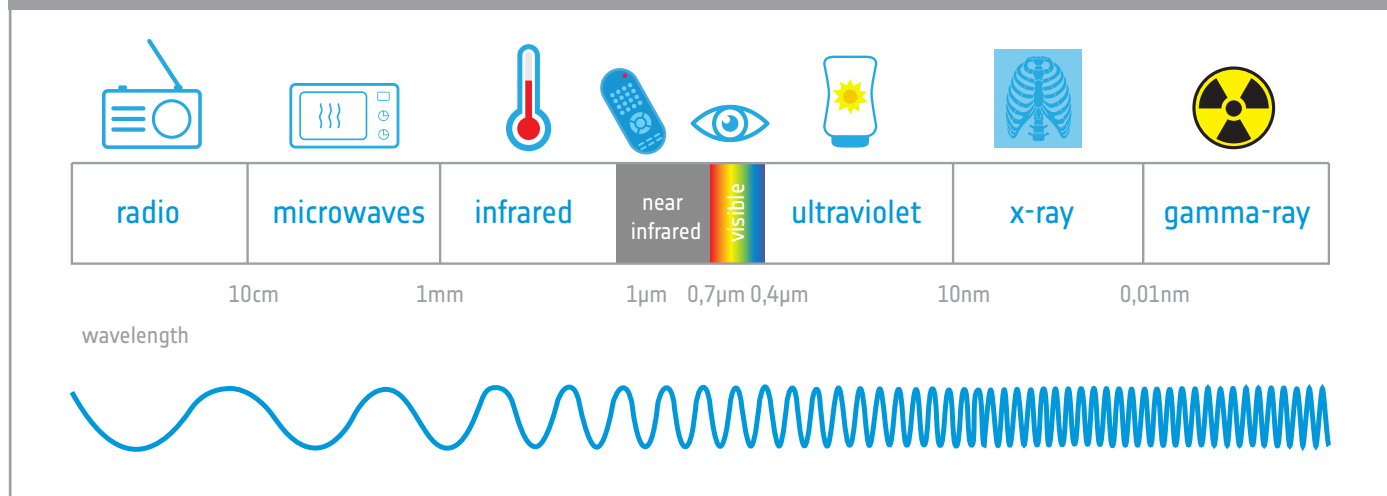
These practical activities can be used to discuss the electromagnetic spectrum, Earth observation applications, and the monitoring of vegetation on our planet. The activities also provide a setting for the discussion of the impact of space technology on our future and on our everyday lives.

→ INFRARED WEBCAM HACK

Using infrared light to observe the world in a new way

Our eyes can't see infrared light, but we can use an infrared camera to see this 'invisible' light. The light we can see – visible light – is only a very small part of the electromagnetic spectrum. Figure A1 shows the different types of radiation and their wavelengths on the electromagnetic spectrum and gives examples of what certain wavelengths are used for.

Figure A1

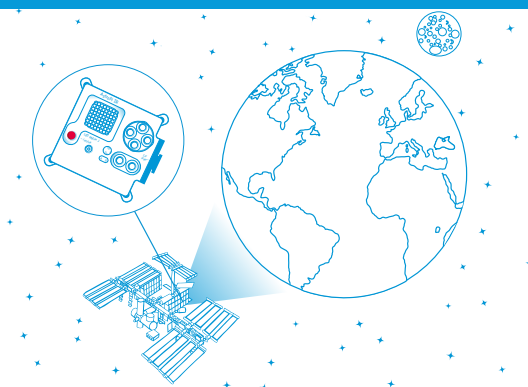


↑The electromagnetic spectrum categorises different types of radiation in order of wavelength, from the longest (radio) to the shortest (gamma-ray)

Infrared light is divided into different parts, just like visible light is divided into different colours. Near-infrared light, the part closest to red light, can be easily detected by the sensors used in digital cameras. Also Earth observation satellites carry scientific instruments designed to detect electromagnetic emissions from constituents of the Earth's surface and atmosphere allowing us to observe our planet in a new way.

Did you know?

Onboard the International Space Station (ISS) there is a very special infrared camera that can be used to take great pictures of Earth! The infrared camera is part of Astro Pi, a small computer with a set of sensors and gadgets that can be used to run great scientific experiments. Teams of students can program this small computer by participating in the European Astro Pi Challenge and use the Astro Pi's near-infrared camera to measure, for example, the health and density of vegetation on Earth.



→ Activity 1: Hacking the webcam

In this activity you are going to make an infrared camera by hacking a normal webcam. Usually, in all digital cameras and webcams there is an infrared filter behind the lens that filters out all infrared light in order to mostly capture visible light. This filter needs to be removed. Here you find simple instructions on how to hack your webcam to be able to see in near-infrared.

Equipment

- 1 webcam with a manual focus ring on the front
- 1 pin or scalpel
- 2 pieces of exposed photographic film or polarising filter
- Clear tape
- Scissors

Exercise

1. Disassemble the camera

Unscrew the focus ring in an anticlockwise direction until the whole lens can be pulled out.

2. Remove the infrared filter

On the inside of the lens there is a small piece of plastic with a red/green tint (see the left lens in Figure A2). This is the infrared filter. Using a pin or a scalpel, remove the filter. Be careful: this should be done very gently, as the filter can break if too much pressure is used.

3. Assemble the camera

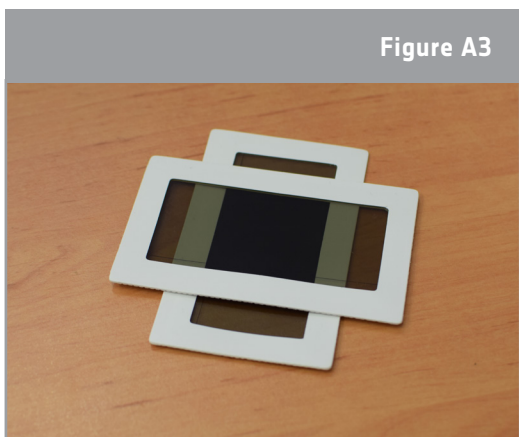
Screw the lens back onto the webcam and plug the webcam into a computer. It may be necessary to open video software to view an image through the webcam. Use the focus ring to adjust the focus until you have a clear image of the object that you wish to look at.

Figure A2



↑ How to make an infrared camera.

Figure A3



↑ Polarising filters.

The infrared webcam is now ready to be used!

Tip: If your image appears very bright on the screen, there is too much visible light which needs to be filtered out. For this, two pieces of polarising filter or exposed photographic film have to be put in front of the lens. Make sure the two pieces are put on one another perpendicularly. The filters can also be fixed with clear tape.

→ Activity 2: Looking at objects with an infrared camera

In this activity, you will use the hacked infrared webcam to make your own experiment about how objects look like when seen with visible and infrared light.

Equipment

- Infrared camera (from activity 1)
- Remote control
- Led light
- Candle
- Healthy plant and fake plastic plant

Exercise

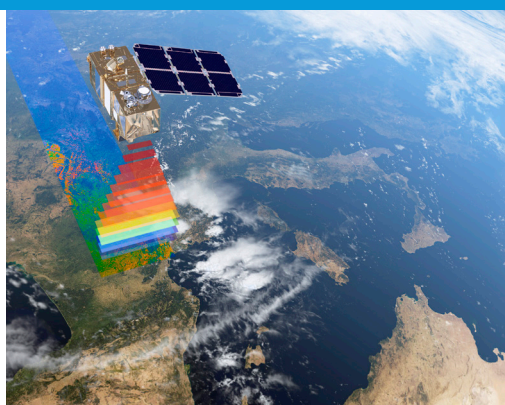
1. Look at the different objects firstly with your eyes (visible light) and then through the webcam (infrared light).
2. Fill in the table on the next page with your observations.



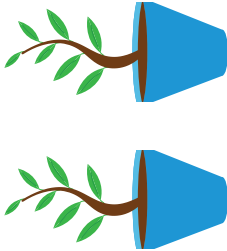
Discussion

Taking into consideration the results from your experiment, discuss with other students how infrared light can help us better understand what we see. Summarise your conclusions below.

Did you know?

The European Space Agency (ESA) has helped develop lots of satellites that use different types of cameras for looking at Earth. A group of missions called the Sentinels aim to improve our understanding and management of the Earth's environment. One of the missions is called Sentinel-2 and consists of two twin satellites. The cameras onboard the satellites take images in visible as well as in infrared light, and they cover the whole planet every five days! Sentinel-2 can be used to monitor plant growth, map changes in land cover, and monitor the world's forests.



Objects	Describe your observations		Explain your observations
	Visible light	Infrared light	
Remote control 			
LED vs. candle 			
Living vs. fake plants 			

→ Activity 3: Looking at Earth in infrared light

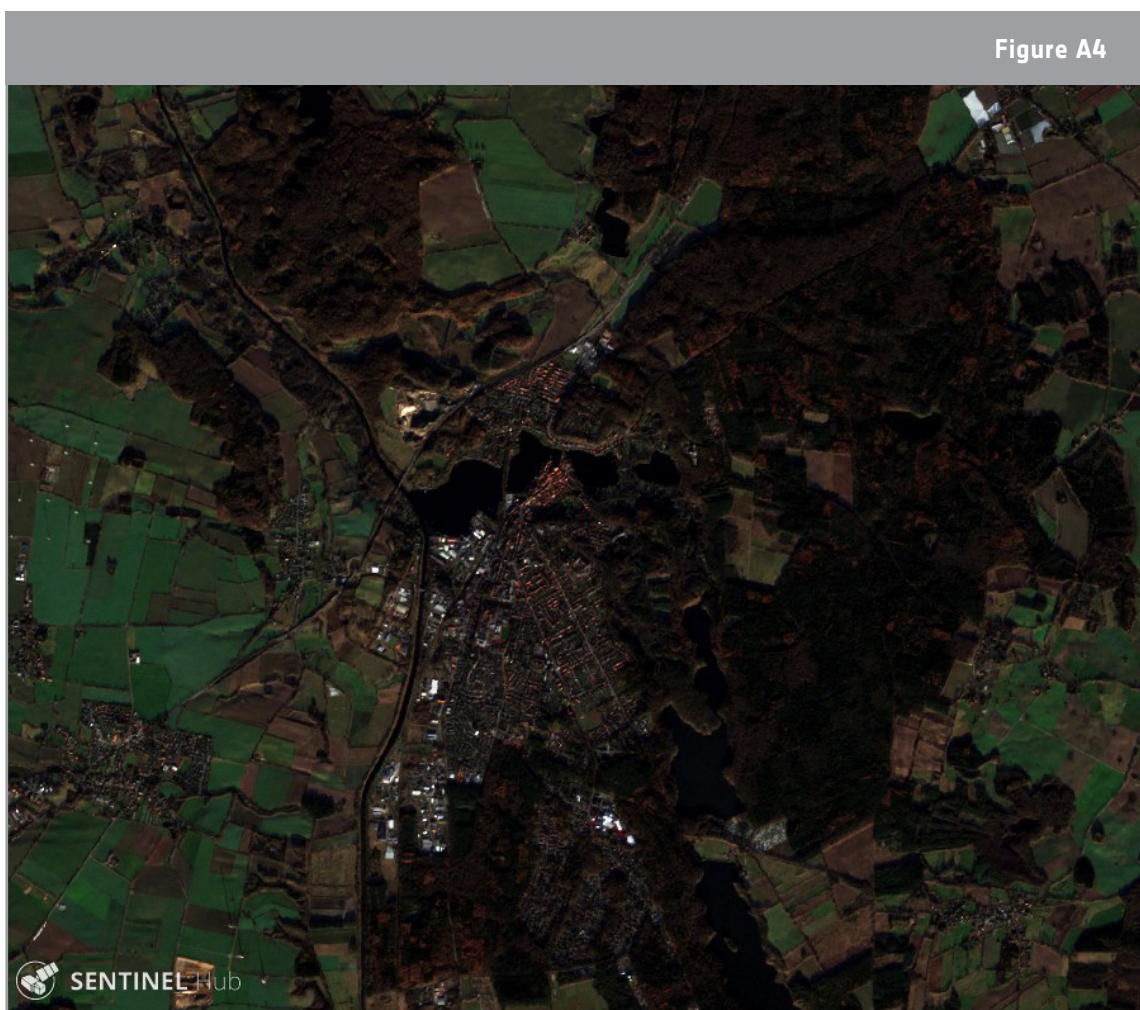
Infrared cameras are used in Earth observation satellites. With the help of computers, we can then visualise the light we cannot see with our own eyes. What comes out is a 'false colour image'. If we display the light visible to human eyes, we call it a 'true colour image'. A true colour image combines actual measurements of reflected red, green, and blue light, and shows the world as we see it. A false colour image uses at least one wavelength outside the visible range. As a result, the colours in the final image may not be what we expect them to be. For example, grass is not always green!

In this activity you will analyse satellite images and compare true colour images with false colour images. Will you be able to find the differences?

Exercise

1. Observe the true colour image below taken by the Sentinel-2 satellite (Northern Germany, 28.11.2016). Which of the following features can you identify?

- | | |
|----------------------|-------------|
| • Agriculture fields | • Lakes |
| • Snow | • Streets |
| • Forest | • Cars |
| • Clouds | • Buildings |
| • River | • People |



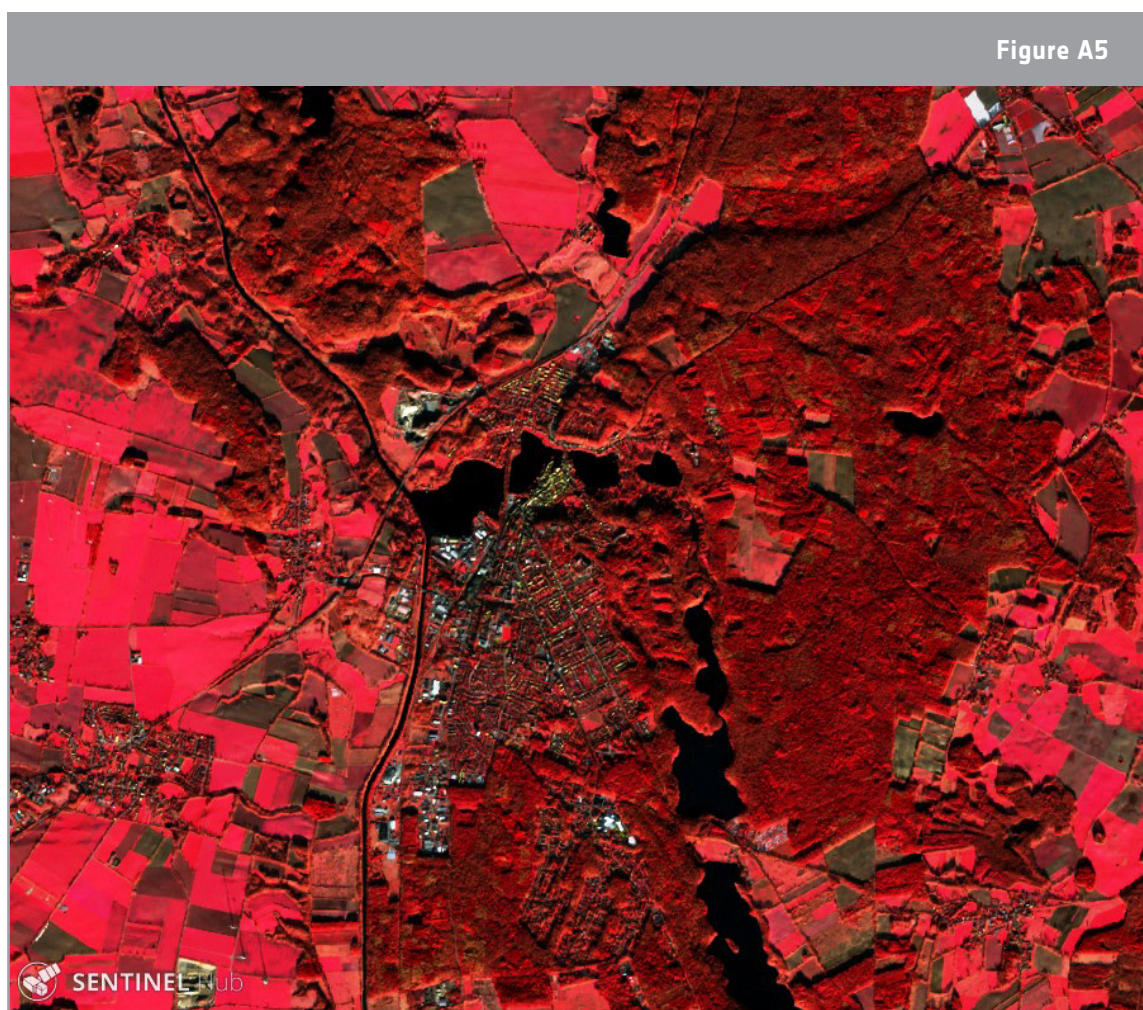
↑ True colour image taken by the Sentinel-2 satellite. Contains modified Copernicus Sentinel data [2017] processed by Sentinel Hub.

2. Observe the false colour image taken by the Sentinel-2 satellite (Northern Germany, 28.11.2016).

Note: The false colour image shows reflected near-infrared light as red.

- a. Try to find the features you previously observed. Can you also identify new features?

- b. What surface type/feature appears red in the false colour image? Distinguish between bright red and dark red.



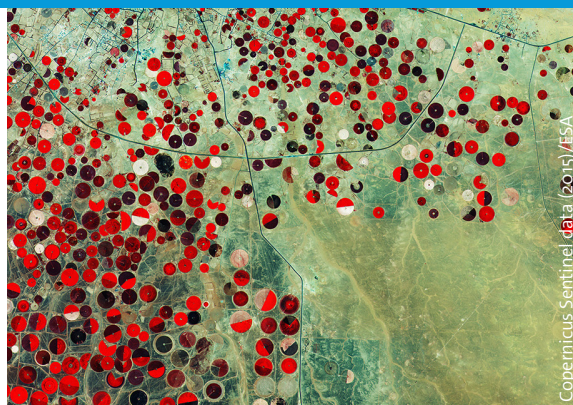
↑ False colour image taken by the Sentinel-2 satellite. Contains modified Copernicus Sentinel data [2017] processed by Sentinel Hub.

3. Describe the differences and similarities between the true colour image in Exercise 1 and the false colour image in Exercise 2.

4. Discuss the advantages and disadvantages of the true colour images and the false colour images showing near-infrared light.

Did you know?

This image from the Sentinel-2A satellite shows how Saudi Arabia's desert is being used for agriculture. The circles come from an irrigation system, where the long water pipe rotates around a well at the centre. It is a false colour image and the near-infrared is displayed in red. Plants reflect most of this light. These high reflection values explain the bright red of the irrigated fields. Near-infrared light is often used to monitor vegetation from space.



→ Links

ESA resources

ESA teach with space – infrared webcam hack video | VP15:

esa.int/spaceinvideos/Videos/2017/06/Infrared_webcam_hack_-_using_an_infrared_webcam_to_observe_the_world_in_a_new_way_-_classroom_demonstration_video_VC15

ESA classroom resources:

esa.int/Education/Classroom_resources

ESA space projects

ESA's Earth Observation missions

www.esa.int/Our_Activities/Observing_the_Earth/ESA_for_Earth

Sentinel -2

www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-2

Extra information

Online platform to access satellite imagery

<https://apps.sentinel-hub.com/eo-browser>

Video Sentinel-2: an introduction

esa.int/spaceinvideos/Videos/2015/07/Sentinel-2_an_introduction

ESA Earth Observation Image of the Week

esa.int/spaceinimages/Sets/Earth_observation_image_of_the_week