

Slide 1 – Title Slide

Hello and welcome to Week 10, part 4 of EGM310: Sensor distortions and corrections. In this lesson, we'll learn about how cameras and sensors lie – that is, how they distort the data they record – and how we can correct those distortions.

Slide 2 – From Sensor to image

You may know that the images you take with a camera have some level of distortion – that is, they don't perfectly represent reality. Cameras can introduce a geometric distortion – objects in an image have a different shape than in the real world. One example shown here shows this using two different lenses, a curvilinear lens and a rectilinear lens. With the curvilinear lens, the fence in the foreground appears to be curved. With the rectilinear lens, which stretches objects to make them appear straight, the fence in the picture is straight; we can also see the influence on the shape of the stand of trees in the background. This image comes from an article in a photography magazine, which I've linked to at the end of the lesson. In addition to geometric distortion, we can have radiometric distortion – that is, the 'color' of an object in the image appears differently than it does in reality. This example shows a scanned air photo, and you can see how the scanner has introduced stripes into the image that don't exist in reality. As I've mentioned, these distortions can have different causes. These can be systematic causes, meaning that the distortion behaves in a predictable way that we can model and correct; they can also be non-systematic, or random, which can be more difficult to correct. For most remote sensing applications, we need images that have a consistent geometry; in other words, the same object in different images will have the same shape and size. We also need images to have a consistent radiometry; that is, we want color differences in an image to be due to actual differences in the objects on the ground, and not differences in the sensor.

Slide 3 – Geometric distortion

Geometric distortion can have a number of sources. Because the Earth's surface is curved, representing it on a flat image stretches and distorts the surface toward the edges – similar to the way different map projections distort the Earth's surface in different ways. As a sensor is scanning the surface of the Earth, the Earth is rotating underneath the sensor. Thus, the beginning of successive scans won't actually line up, as the Earth surface has rotated in the time it takes to scan each line. Satellites don't fly in completely perfect orbits, either – small variations in the orbit can lead to differences in the image geometry. As we covered in the lesson on passive sensors, the way the sensor acquires an image can also cause distortion which has to be corrected. Atmospheric refraction can also cause objects to appear distorted or shifted in space. Depending on the resolution of the image, this can be something that we need to account for. And finally, Earth's terrain causes geometric distortions through something called relief displacement. To properly map and study Earth's surface features using remotely sensed images, these are all things that we have to account for. Fortunately, most of these different factors are already corrected by the time we download a satellite image, but this isn't always the case.

Slide 4 – Relief displacement

At nadir – that is, directly underneath the sensor, the sensor sees the top of an object. As we move away from the nadir track of a satellite image, objects will appear to lean away from the nadir track. We can see this in the example here, which shows Mount Ranier in the United States. In the image on the left, the mountain is centered within the image. If we then re-project the image to simulate an observation at 30 degrees off-nadir, the mountain is no longer centered. The side of the mountain closer to the sensor is stretched, while the side of the mountain further away from the sensor is compressed. How much objects in an image appear to lean depends on how tall the object is, and how far away from nadir the object is. If we know the elevation of the objects in a scene, we can estimate and correct the relief displacement. This process, known as orthorectification, is a necessary pre-processing step for accurately estimating areas, shapes, and locations in satellite images.

Slide 5 – Geometric corrections

One way that we can correct the geometry of an image is by finding ground control points, or GCPs – that is, points whose exact location and elevation is known. On the left here, I have a raw satellite image, as the scanner sees it. On the right, we have an image for the same area that has been fully processed and orthorectified. So, in our GIS software, we could look for points that we can easily identify in both images. For example, we can start with this small spit here in the lower left portion of the image. We might also look for a point at a higher elevation, such as this mountain peak here. The island here in the lower right part of the scene could make another good control point. And we can keep going like this, finding points that are spread out across the scene, and that represent a range of elevations.

Slide 6 – Geometric corrections

With our GCPs, we can calculate a mathematical transformation between the image and the map geometry. We can then re-sample, or interpolate, the image into the corrected geometry. What kind of algorithm we use for the re-sampling will depend on the kind of data we're using. The textbook chapters listed at the end of the lesson provide more information about some of the common interpolation algorithms used – I won't go into detail on them here. Depending on the kind of transformation, we may also need to correct for terrain displacement or other distortions at this stage. At this stage, we can also use additional GCPs to estimate the geometric accuracy of the image.

Slide 7 – Radiometric distortion

Like geometric distortion, radiometric distortion has a number of causes. This can include sensor degradation or failure. For some of the earlier Earth observation satellites, errors or interruptions in transmitting sensor data to ground stations would cause missing lines, as shown in the example here. As sensors age, the detectors use also age, which can cause differences that need to be corrected. Different sensors may also have different characteristics – if we want to compare them, we need to somehow correct for these differences. Differences in scene illumination can also cause radiometric differences

that need to be corrected or accounted for. Atmospheric conditions can differ between images as well, leading to different amounts of refraction or scattering that may need to be corrected to properly compare images or identify objects. Finally, topography can also play a role – for example, due to shadowing or increased specular reflection off of surfaces, such as mountain slopes, that face the sensor.

Slide 8 – Striping

As mentioned, detectors can have different responses that need to be calibrated. This can be due to a change in detector response over time – that is, the detector may record lower levels of radiation as it ages and the materials in it degrade; or it can be due to differences between different detectors in the same sensor. Remember that linear array sensors (“pushbroom” sensors) are made up of many thousands of individual detectors that are not perfectly similar – they all have to be calibrated to make sure that they record in a similar way. Some sensors, such as the Advanced Spaceborne Thermal Emission and Reflection Radiometer, or ASTER, provide calibration data that can be used to correct the images. In the example shown here, you can see stripes in the image that are caused by individual detectors recording different levels of radiation. Using the calibration information provided with the image, we are able to correct this striping. If the sensor does not provide calibration information, we can also use a variety of filtering or image processing techniques to help correct some of these issues, such as the striping shown here.

Slide 9 – Atmospheric correction

Remember that because of scattering in the atmosphere, some electromagnetic radiation is sent back to the sensor from the atmosphere. As a result, the sensor is actually measuring what’s known as the “at-sensor” or “top of atmosphere” reflectance. Most often, what we want is the surface reflectance – the electromagnetic radiation that is reflected by the surface alone. This means that we need to somehow model or estimate the atmospheric reflectance so that we can remove it. This can be done using an atmospheric transfer model that models the atmospheric components and estimates the amount of scattering, or using another sensor with a larger number of bands, which can be used to estimate the amount of scattering based on the atmospheric conditions at the time. We can also use the different bands within a scene to estimate atmospheric scattering, although this is usually a less exact process.

Slide 10 – Summary

In this lesson, we learned that images will have distortion, either radiometric or geometric.

In order to compare images at different times or different places, we need to correct these distortions.

These distortions can have different causes. Systematic distortions are predictable – we can use a mathematical model to estimate them and correct them. Non-systematic distortions are random – we can correct them, but we usually have to use external data to estimate them.

Slide 11 – Additional Resources

Once again, you can read more about the concepts we've covered in this lesson in the textbooks, Chapter 7, section 2 of Lillesand, Kiefer & Chipman; and Chapter 11 of Campbell & Wynne. The Natural Resources Canada Remote Sensing Tutorials also has a section about geometric distortions, which you can read at the link on the slide, or in the description below. Finally, I've linked to the article on lens distortion, which discusses camera distortions in more detail. That's all for this lesson – I hope you found it interesting, and if you have any questions, please don't hesitate to e-mail me or post in the discussion forum on blackboard. Bye!