Slide 1 – Title Slide

Hello and welcome to Week 3, Part 3 of EGM703: Principles of radar. In this lesson, we'll learn all about radar and radar remote sensing.

Slide 2 – Radar: the basic idea

Radar is a word that originally stood for "Radio Detection and Ranging", though at this point it's just a noun. It's an active microwave remote sensing system – this means that the source of the signal that we're measuring comes from the satellite itself, rather than being supplied by the Sun or emitted by the target we're looking at. The basic idea behind radar is that we send out a signal from the satellite, or transmitter, and we measure the signal that comes back. When the signal comes back to the receiver, we know how long it took to come back, which means we can work out how far away the target is: the distance, or range, R, to the target is just the speed of the signal, multiplied by the travel time, divided by 2. We also measure the signal strength, or amplitude, which tells us something about how much energy is reflecting off of the target. We can also measure the polarization of the signal that comes back – many radar satellites, for example, will transmit a signal in one polarity and measure the return in a different polarity, which tells us something about the target. We might also measure the partial wavelength, or phase, of the signal that comes back – this is especially useful for some applications that we'll talk about next week. And finally, we might measure the frequency of the signal, to see if there has been any change from the signal we sent out.

The radar equation, shown here, tells us how the power received by the sensor, P_r, depends on a number of different factors. These include the power transmitted, P_t; the antenna gain, G, which tells us how well the antenna transmits the received signal into electrical power that can be recorded; the distance to the target, or range; and finally, the radar cross-section of the target, σ.

Slide 3 – Range resolution

We've already established that range is just the distance between the sensor and the target – it's where we get the 'ranging' in 'radio detection and ranging.' But now, we want to think about the range resolution – that is, how well we can distinguish between two different targets, using our radar system. As an example, if we have two targets here that are close together, and we send a radar signal towards them, when the signal comes back to the sensor, it will record a signal like this from the closer of the two objects. And then, a very short time later, it will record the return from the second object. If the targets are too close together, these peaks will overlap and we won't be able to tell the difference between them – it will look like one wide return peak. On the other hand, if our targets are slightly further apart, like this, the first return will look like this, and the second return will come just a bit later, and we'll be able to see that these are in fact two peaks. It turns out that the range resolution of our sensor depends partly on the bandwidth of the transmitted signal. The shorter the signal, the better our ability to tell the difference between different returns. The formula for it is here: it's the bandwidth multiplied by the speed, divided by two (because we're going there to the target and back again). Since the speed is fixed, the only thing we can change is how “wide” the signal is – we’ll talk a little bit more about how we do this in practice later on.

Slide 4 – Types of radar systems

We can differentiate between the different types of radar systems that we use for remote sensing, based on what kind of measurement they make. Non-imaging radar systems can be broken into two categories: radar altimeters, which measure distance – the example here of a satellite radar altimeter shows the basic idea here: the satellite sends a signal to the Earth’s surface and measures the time it takes to return. If we know the satellite’s position and look direction, we can then calculate the height of the surface. The other main type of non-imaging radar is called a scatterometer, which measures the signal scattered back to the sensor. As you might have already guessed, the other main category of radar system is an imaging radar. These systems look sideways at the ground; as the sensor moves, it builds an “image” through repeated measurements, similar to the optical satellites that we’ve studied work. The main types of imaging radars that you might encounter are side-looking airborne radars, which are systems mounted on an aircraft; and synthetic aperture radar, which are most commonly found on satellites. We will cover how SAR sensors work in the next lesson.

Slide 5 – Radar altimeters

As mentioned, radar altimeters are used to measure the distance between the satellite and the Earth’s surface. Radar altimeters can achieve very high accuracy – down to as little as 3 centimeters difference, which is rather impressive given that we’re making these measurements from around 700 km away! The large footprint of the altimeter signal, however, means that we’re limited to measuring the height of large, relatively “flat” surfaces such as the ocean or the interior of the ice sheets. Among other applications, radar altimeters are used to map bathymetry over large stretches of the ocean – because underwater ridges and structures exert a gravitational attraction, water will essentially “pile up” over high points; over trenches and other low points, we see depressions on the surface. Because altimeters can map small changes in elevation, we can use this to calculate the depth of the water, after accounting for waves, tides, currents, and atmospheric effects.

Slide 6 – (Radar) Scatterometers

Radar scatterometers detect the signal that is scattered by the Earth’s surface – that is, they measure the radar cross-section, sigma nought, of the surface. The main application we see for radar scatterometers is in measuring wind speed over the ocean. Recall that sigma nought depends on the surface roughness and the viewing angle - in the diagram here, you can see how this satellite, the advanced scatterometer (ASCAT), works. It sends out beams in six directions – three on either side of the satellite. The ocean roughness depends on the near-surface wind speed – wind creates small “capillary” waves that change how the signal is scattered back to the sensor, and we can relate the measured backscatter to the wind speed. When we have different viewing angles, we see different amounts of backscatter, which means we can work out the wind direction. The example image here, from EUMETSAT, shows the measured wind field of hurricane Matthew in September 2016 – we can clearly see the spiral pattern of the storm, measured over a very large area.

Slide 7 – Imaging radars

Now, we come to imaging radars. Imaging radars are tilted to the side, rather than looking straight down – this is so that we can make measurements at different distances, or range, along the ground. The signal from objects further away in the slant range is recorded later: as the signal goes out, the wave front expands in a circular shape (at least, when viewed in two dimensions). So, the signal from the house shown here will be returned first, and the signal from the tree will come back later. Using trigonometry, we can transform the distance in the satellite's look direction, slant range, to ground range, or the distance along the ground from the satellite path. As the antenna moves along the flight direction, or azimuth, it continues recording, which means we can effectively build an image one line of pixels at a time.

Slide 8 – Range compression

One problem with sending signals is that sending a signal, or pulse, that's powerful enough to return a detectable signal from space, while also being short enough to give us a good range resolution, is very hard. Fortunately, we do have a solution to this problem – we can make it unique! Rather than transmitting a pulse that's just a single peak, we instead transmit a signal with a frequency that changes over time, like this – known as a chirp. The change in frequency from the start of the pulse to the end of the pulse is the inverse of the bandwidth, τ_P, of the signal. When we receive signals, it's important to remember that we're getting returns from many different surfaces all at once – the result is very noisy, and it can be difficult to actually find our signal. By correlating the signal that we sent with the signal that we recorded, a process known as 'range compression', we can actually find the signal that we sent out – and more importantly, the time that it was recorded. This helps us solve the problem of the overlapping signals, and means that we can actually create high-resolution radar images from satellite sensors. For systems that send frequency-modulated chirps, the range resolution is then inversely proportional to the frequency range – so, the more that we change the frequency of our pulse, the better the resolution we get. It turns out that this is much easier than sending a short pulse that's powerful enough to be recorded by a satellite sensor.

Slide 9 – The Doppler effect

The last concept we'll introduce in this lesson is the Doppler effect. If the source of a wave is moving – for example, stars in distant galaxies or cars making sound on the motorway – that motion actually causes a shift in the frequency of the signal being sent out. An example that is hopefully familiar to you is an ambulance with its siren on. That siren is making sound waves that propagate radially away from the ambulance, like the circle shown here. But, a few seconds ago, the ambulance was a little bit further back – the sound wave it made at that location is centered there, so it looks like this relative to its current location. And, a few seconds before that, it was here, so the sound wave from that point in time will look like this, and so on. If we're observing the ambulance here, where the ambulance is moving towards us, we see how these sounds waves are essentially being compressed, or pushed together – the frequency that we observe is increased, relative to the original frequency. If we're on the other side here, observing the ambulance moving away from us, we see how the frequency we observe is going to be lower than the original frequency. If we know the original frequency, we can calculate the velocity of the source relative to the observer, based on the observed frequency. This is the principle behind things like the radar guns used to measure vehicle speeds on the road. Alternatively, if we know the relative velocity of the source (for example, a satellite), we can calculate the shift in frequency, which will also help us determine where on the ground a signal was returned from.

Slide 10 – Summary

In this lesson, we've discussed how radar is active remote sensing: the satellite is actually sending out the signal and measuring the return.

The signal that we measure depends on the properties of the target, such as the normalized radar cross-section, as well as the properties of the signal that we send out.

We covered the two main flavors of radar systems that we use in remote sensing: imaging and non-imaging radars, which provide one-dimensional or two-dimensional measurements, respectively.

And finally, we covered how with some neat signal processing techniques, we can improve the range resolution of our radar system – that is, how well we can distinguish between targets at different distances to our sensor.

Slide 11 – Additional resources

You can read more about the topics we've discussed here in the textbooks – Lillesand, Kiefer & Chipman, Chapter 6, or Cambpell & Wynne, Chapter 7. This website, radartutorial.eu, has a number of good explanations and visualizations for some of the concepts that we've covered here, and also provides a lot more information about the different systems that we might see. For more information about how we can measure surface wind speed from space, this page from EUMeTrain is worth a look. And finally, I've linked to two videos made by ESA that explain why radar satellites are so important, and also how radar altimeters are used. That's all for this lesson – I hope you found it interesting, and you have any questions, please don't hesitate to e-mail me or post in the discussion forum on blackboard. Bye!