Radar

Few technologies have been as widely applied as radar. From detecting enemy planes to giving advanced warning of a tornado, radar has become a crucial technology in the modern world.

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What is radar?

RAdio Detecting And Ranging – or radar – is a method for the detection of distant objects and the determination of their position and velocity. At the most fundamental level, the radar method involves sending radio waves out to a suspected obstacle and timing how long the waves take to return once they are reflected off that object. This allows the determination of distance between source and obstacle.

As its name would indicate, the method originally used the radio portion of the electromagnetic spectrum, with wavelengths approximately between 10 and 13 m. As knowledge in the field progressed, the low resolution associated with such large wavelengths motivated a decrease in the wavelength being used, with current radars using wavelengths from as small as 1 mm up to 1 m. This means that most modern radar systems actually use the microwave and very high infrared portions of the electromagnetic spectrum, and the definition has been expanded to accommodate this.

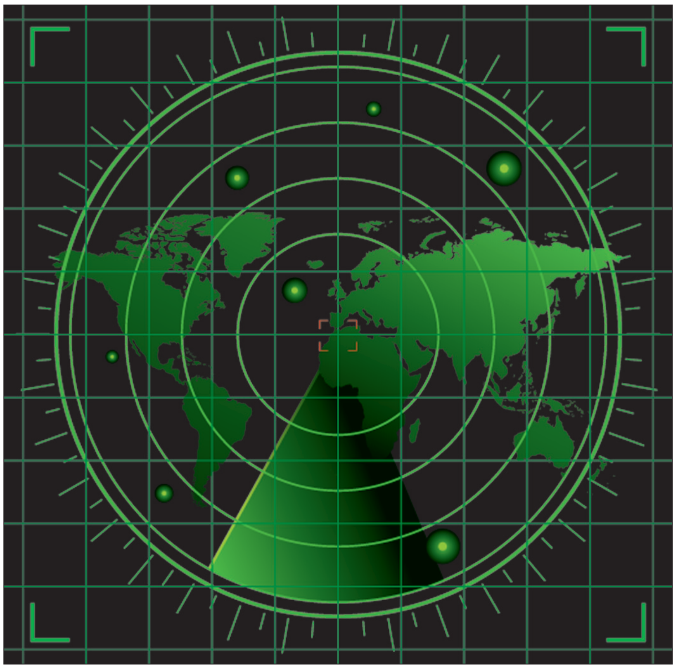
Radar was first fully exploited by the British Army in the 1930s as an enemy-aircraft detection technology. Today the military uses radar in fields such as transportation, astronomy and meteorology. Radar is embedded in contemporary, everyday life through use by commercial airliners, car companies and weather forecasters, and is most recently being utilised to understand climate change and the effect of solar winds on Earth technologies, such as GPS systems.

The science

Radar is a typical example of a technology that developed significantly later than the original physics behind it. Radar systems utilise the electromagnetic spectrum, which was described mathematically by British physicist James Clerk Maxwell in 1873. Radio waves were successfully generated and detected in a laboratory as early as 1887, by German physicist Heinrich Hertz, and transmission tests over ever longer distances were carried out by Italian physicist Guglielmo Marconi at the end of the same century.

Although wireless telegraphy immediately thrived as a result of these tests, it was not until just before the Second World War that radio waves were exploited as a means of detection and defence. The British Army wanted more time for anti-aircraft defences to prepare for an airborne attack. Although "sound detection" facilities involving giant concrete mirrors and microphones were built in the 1920s and 1930s, they had a short range and high winds could render them unworkable. What was really needed was a system that could not only detect an aeroplane, but also how far away it was. In 1935, British engineer Sir Robert Watson-Watt proposed a system for reflecting pulses of radio waves off aeroplanes to determine their distance from the transmitter. The technology was then swiftly tested and a patent was obtained.

By the time the threat of German bombers became real in 1939, 19 radar stations had been built along the east and south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coasts of England, increasing to more than 50 by the end of the war in 1945. Collectively they were known as the Chain Home, and this unique early-warning system was instrumental in the outcome of the Battle of Britain.

Radar scientists working on wartime radar systems went on to use the technology in fields as diverse as astronomy and meteorology. For example, in 1945 English physicist Bernard Lovell set up radar equipment at Jodrell Bank in Cheshire to investigate the echoes that he had sporadically heard during the war. These echoes were in fact the first radar observations of meteors.

The actual mechanics of radar are, as with most timeless inventions, wonderfully simple. A transmitter generates a radio signal using an oscillator, and this signal is sent to the dish/antenna, via a waveguide. The waves propagate through space and are reflected back to the radar station if they encounter an object. The receiver then teases out the main signal from the background noise (e.g. reflections from a passing flock of birds) and amplifies it for processing. If the radar system uses the same antenna to send and receive radio signals, a device is employed to switch between the applications after a signal is sent out.

Because the speed of an electromagnetic wave is constant, and we can measure the time that it takes to return, we can simply multiply the two (halving the time because it is a return journey) and determine that there is an object a certain distance away. Of course, there are now computers to carry out this type of calculation and display it in a user-friendly way – for example, a blip on a circular screen with distance markers.

To measure the velocity of an object, the Doppler method is utilised. When an electromagnetic wave is reflected off a moving object, the wavelength of that wave is changed, or "Doppler shifted". The extent of the shift can be measured and converted into the line-of-sight velocity of the object.

Advanced radar techniques are still being developed today, with different methods allowing ever more accurate images or faster data collection. The principles behind radar have diffused into other scientific areas. For example, American scientist Edward Purcell used his knowledge from working with radar during the Second World War to consider what would happen when radio waves were absorbed and emitted by individual molecules. The nuclear magnetic resonance (NMR) that he observed in condensed matter led to unprecedented knowledge of the chemical and structural nature of individual molecules, and led to such essential technology as MRI machines. Although NMR is a physically distinct process to radar, Purcell's work on radar was crucial to its discovery.

Applications

● *Military*
Military entities globally rely on radar technology. As well as aircraft warning systems – both on the ground and on fighter planes – radar is used just as much in the clean up after a conflict. In areas such as the former Yugoslavia, airborne ground-penetrating radar helps to detect long-forgotten landmines and allows them to be safely destroyed. The radar tracking of possible hostile airborne objects aims to give an early warning of an incoming missile and also calculate its origin.

● *Meteorology*
Through the detection of meteorological objects, radar has become an important tool in weather forecasting, with 15 UK Met Office radar stations currently in existence. By matching radar patterns with observed weather in different locations, we can construct more advanced computer models and thus forecast more accurately. For instance, the air movements seeding a tornado leave a distinct signature on a Doppler radar, which, if detected, can be used to give warning and save lives.

● *Transport*
Aeroplanes are now routinely equipped with radar systems to warn of nearby objects, give accurate indications of altitude and allow safe landings in fog and other difficult weather conditions. Similar radar obstacle-warning systems are fitted on marine vessels and, on a smaller scale, road vehicles. Marine traffic service vessels and air traffic control units use the technology to help monitor busy transport routes. Police routinely use Doppler radar guns to identify vehicles travelling over the speed limit, helping to enforce road safety.

● *Astronomy*
Historically, radar independently detected Saturn's rings and Jupiter's Galilean moons. Radar has allowed the study and tracking of near-earth asteroids and ground-penetrating radar has provided a surface roughness map of Mars to help find suitable landing sites. The European Incoherent Scatter (EISCAT) Scientific Association – funded in part by the UK – operates three radar systems, which study the interactions between the Sun and the Earth by measuring atmospheric changes. Radar astronomy should not be confused with radio astronomy, where the radio signal received is originally emitted by a celestial object and not a synthetic source.

● *Geophysical radar*
Radar systems flown at high altitude or on satellites have provided intricately detailed topographic maps of the Earth's surface, revealing inaccessible polar terrain and elevation data hidden below forest canopies. A handheld radar at the top of Mount Everest was able to penetrate the snow and provide an accurate height measurement of the mountain. Radar can also be used to document changes in the Earth's surface. Satellite-borne radars, such as the European Space Agency (ESA) satellite CryoSat, help to monitor the melting of the polar ice sheets, and portable radars such as AVTIS can measure how a volcano is

Timeline

1873	British mathematical physicist James Clerk Maxwell publishes equations that unify theories of electricity and magnetism.
1883	Irish physicist George Fitzgerald suggests that an oscillating electric current will produce electromagnetic waves.
1886	German physicist Heinrich Hertz generates and detects the first synthetic radio waves.
1896	Italian physicist Guglielmo Marconi demonstrates transmission of radio waves across Salisbury Plain.
1901	Guglielmo Marconi transmits the first wireless signal across the Atlantic Ocean.
1904	German engineer Christian Huelsmeyer demonstrates the use of radio echoes to detect ships but due to lack of interest his “telemobiloscope” is not put into production.
1924	Edward Appleton and Miles Barnett in the UK use an FM radar technique to measure the height of the ionosphere.
1934	French engineer Émile Girardeau obtains a patent for a working radar system and installs it on an ocean liner.
1935	British engineer Sir Robert Watson-Watt demonstrates and patents a radar device for detecting passing aircraft.
1937	The first three British radar stations are completed and another 17 are ordered, creating the Chain Home.
1938	German radar chain Freya is activated. However, it consists of only eight stations, has a smaller range and cannot accurately determine altitude.
1940	The term RADAR is coined by the US Navy.
1940	British physicists, John Randall and Harry Boot of the University of Birmingham, invent the cavity magnetron; a small device that allowed the development of practical centimetric radar, which could detect smaller objects using smaller antennas. The cavity magnetron played a major part in the Allies’ victory.
1945	The end of the Second World War sees a Chain Home consisting of more than 50 radar stations along the south and east coasts of Britain.
1946	The Moon is independently detected using radar.
1953	Electrical engineer Donald Staggs of Illinois State Water Survey makes the first radar recording of a hook echo – the signature of a tornado-causing supercell.
1955	Douglass Crombie identifies ocean signature in HF radar backscatter.
1959	Vanguard 2, the first weather satellite, is launched.
1961	Venus is independently detected using radar, providing independent measurement of an astronomical unit.
1973	Tornado vortex signature is discovered after the first documentation of a tornado life cycle using Doppler weather radar.
1994	The University of Leicester constructs two Arctic radars leading to the formal creation of SuperDARN.
2009	HMS *Daring*, containing one of the world’s most advanced radar systems, is launched.
2010	Latest SuperDARN UK radar comes online in the Falkland Islands. First HF radar for wave-power applications is due to be installed in Cornwall.

changing shape and predict the locations of new eruptions.

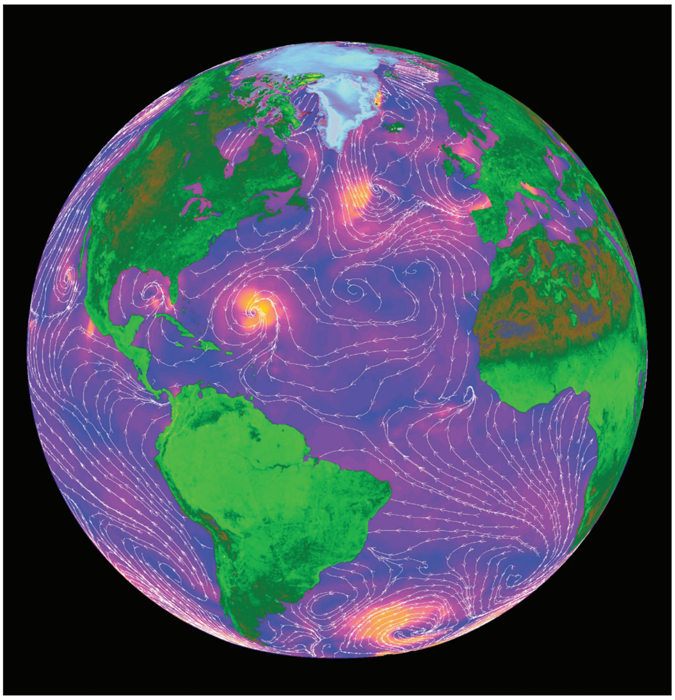
● *Oceanography*
Ocean waves produce a strong sea echo at HF radio frequencies (3–30 MHz). The Doppler signature of these echoes is related to the current on the surface of the ocean, allowing these radars to be used for wave measurement. Ongoing research is aimed at improving the quality and availability of the measurements and in developing user applications, for example, oil-slick tracking, search and rescue, and marine renewables.

Current developments

Radar is continually developing, with new applications still being researched. To fully understand climate change, we must understand the entire atmosphere and the interactions between different atmospheric layers. The international Super Dual Auroral Radar Network (SuperDARN) is a network of 22 radar sites across the Arctic, Antarctic and some mid-latitude sites. The UK is a main contributor and has its own separate initiative, SuperDARN UK, consisting of nine UK institutions with radar sites in Iceland, Finland, the Falkland Islands and Antarctica. SuperDARN UK is proving invaluable in the study of atmospheric interactions and is also gathering important information on how solar winds affect our technology, from GPS satellites to electrical power grids. EISCAT radars are complimentary to SuperDARN radars: the former produce detailed information but in a very local sense, whereas the latter produce less detailed information on a global scale.

To combat the possibility of terrorist attacks at the London 2012 Olympics, there are plans to moor a British Navy Type 45 destroyer in the Thames, providing instant 250 mile radar coverage and an anti-aircraft missile system. The new radar system employed by the destroyer is said to be able to track an object the size of a cricket ball travelling at three times the speed of sound.

Recently, radar has begun to enter the commercial market. Ford announced that, as of 2011, it would be installing advanced “collision warning” units, which use radar to measure relative speed between moving vehicles. The units are carefully designed



to "watch" for vehicles in the driver's blind spot and even trigger "brake support" for slow-reacting drivers. Pocket-sized radar is now available to replace unwieldy radar guns, and is being sold as a sports gadget to measure baseball pitch speeds and race-car speeds. In 2010, Nokia released a prototype radar-enabled phone, which allows the adjustment of volume using hand movements.

As well as use in anti-terrorism efforts, radar technology is also being developed for the London 2012 Olympic events themselves. Research is currently being carried out into adapting traditional military missile-tracking radar systems to track javelins and archery arrows, measuring their speed and the wind influence on trajectory. This joins the Hawk-eye image analysis and radar technology routinely used in cricket and tennis to deliver ball trajectory measurements (and predictions), which is now officially adopted for decision making.

Impacts

It is near impossible to measure the economic impact of radar because it has been solidly integrated into so many businesses and industries for so long that no estimate can be made. Every commercial plane, military plane or boat, police force and weather-prediction service relies on radar to carry out the service it offers safely and accurately. Without early-warning systems for flood-inducing rain, detecting obstacles a few miles from a commercial plane in fog, or identifying landmine-free terrain, the toll on national economies and human life would be significant. More dramatically, the asteroid impact risk assessments made using radar data could one day help to avert a global disaster.

Because of the commercial nature of radar, it is now mostly the territory of private companies to develop more accurate police radar guns or marine vehicle detection units. The British defence company BAE Systems, the world's second largest global defence company, is actively developing what is described as the world's most advanced radar. In 2000, BAE won a contract worth more than £100 m to develop and install the British Navy Type 45 destroyer "SAMPSON" radars. The British company Navtech Radar Ltd is the world's leading developer of commercial off-the-shelf radar units and has been responsible for several "world firsts" in radar technology, including driverless vehicles. In 2010 it was given the Queen's Award for Enterprise.

The University of Leicester constructed two Arctic radars for the SuperDARN network in 1994, at a cost of only £700 000 to government funding bodies. As a result, the UK is at the forefront of research into important space weather issues and climate change, and the university has been awarded contracts to build a further four radars for scientific institutes in Japan and China.

Key facts and figures

- The UK was the first nation to fully exploit radar technology as an aircraft-detection method, just before the Second World War.
- Radar technology is relied on in large areas of UK industry and infrastructure, including weather services, police and military units, and commercial airliners.
- The British company BAE Systems developed a new generation of radar for use in British Navy Type 45 destroyers, a contract worth more than £100 m.
- £700 000 is the cost of the SuperDARN initiative to the UK government in funding, making it a cheap technology for analysing the impacts of climate change, solar winds and space weather.
- The London 2012 Olympics is employing radar both as an anti-terrorism measure and as a sports statistics technology.
- A British company, Navtech Radar Ltd, is a world leader in off-the-shelf radar technology, and in 2010 was given the Queen's Award for Enterprise.

Useful links

- www.bbc.co.uk/dna/h2g2/A591545
- www.superdarn.ac.uk/
- www.purbeckradar.org.uk/penleyradararchives/history/introduction.htm
- www.metoffice.gov.uk/corporate/pressoffice/anniversary/radar.html
- http://en.wikipedia.org/wiki/Radar
- http://en.wikipedia.org/wiki/Radar_astronomy

- Thanks go to Prof. Mark Lester, University of Leicester; Dr Emma Woodfield, Lancaster University; Prof. Hugh Griffiths, UCL; and Emma Woodfield for their help with this case study.

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