WHITE PAPER

Radar in surveillance

Technological background and performance considerations

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1 Summary

Even though it's based on a non-visual technology, radar has a lot to offer in surveillance. Radar works well in many situations where other surveillance technologies might miss alarms or create false alarms, such as in poor lighting, darkness, and fog, or when there are moving shadows or lights in the scene. Radar also helps maintain privacy because people can't be identified from the radar information.

Tracking and classification of objects is integrated in Axis radars, with a deep learning classifier algorithm distinguishing the type of detected object, for example a human or a vehicle. The radar can be set up to trigger a range of actions depending on what it has detected.

Radars can be used on their own, for example in environments where cameras aren't allowed due to privacy concerns. But radar is often integrated in a security system with video and audio devices.

Typical installations include:

- Radars combined with visual cameras — for identification of individuals detected by the radar. This is especially effective with PTZ (pan-tilt-zoom) cameras that can track and identify persons or vehicles based on their exact geographical position provided by the radar.
- Radars combined with thermal cameras — a radar's wide area detection complements a thermal camera's narrow but long detection area.
- Radars and audio devices — where visual identification either isn't allowed or isn't prioritized. A deterring audio message can effectively stop an intruder that is detected by the radar.
- Radar for traffic statistics or driver feedback — a radar can be used to count vehicles or detect speeding vehicles. The radar can be connected to a digital speed sign to provide feedback to drivers.

Axis also offers a radar-video fusion camera, which integrates a radar and a camera in one device. The combination of video analytics and radar analytics enables even better detection, classification, and visualization.

Axis radars operate within the safety limits for public exposure to electromagnetic fields. The emissions are considerably lower than the recommended reference levels during normal operation. This allows for the safe use of multiple radars on the same site without concern for radiation safety.

In the last section of this paper, a comparison table lists the differences and similarities between radars, visual cameras, and thermal cameras. A combination of technologies is often preferred because they have different strengths and limitations.

2 Introduction

Radar is an established detection technology based on radio waves. Developed for military use around the 1940s, radar soon found its way into other markets. Its usage is ever developing, and common applications today include weather forecasting, road traffic monitoring, and collision prevention in aviation and shipping. Modern semiconductor technology enables conveniently sized radar systems-on-chip to be increasingly used in cars and small consumer products. In the civilian security market, radar units can complement video cameras and other technologies to expand and improve surveillance systems.

This white paper provides a brief account of how radar technology works and details specifically how it can be used in security and surveillance. We discuss which factors you should consider before installing a radar, and how these factors affect the detection efficiency. We highlight the pros and cons of radar compared to other security technologies such as video analytics and thermal cameras and show how the different technologies can be combined for optimal surveillance.

3 What is radar?

The term radar was originally an acronym for the more descriptive phrase *radio detection and ranging*. Radar is a technology where radio waves are used to detect objects and determine how far away they are.

3.1 How does it work?

A radar transmits signals consisting of electromagnetic waves in the radio frequency spectrum (radio waves, for short). When a radar signal hits an object, the signal is usually reflected and scattered in many directions. A small portion of the signal is reflected back to the radar device, where it will be detected by the radar's receiver. The detected signal provides information that can be used to determine the location, size, and velocity of the object that was hit.

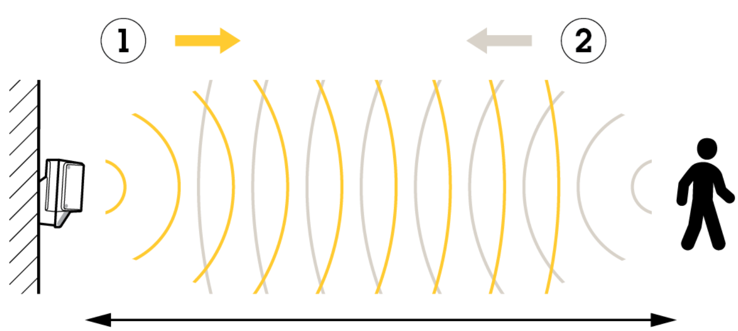

Figure 1. The general principle of radar: a signal (1) emitted from the radar is reflected (2) upon hitting an object.

While employing the same general principle, radars can be constructed to work with either short radio pulses or continuous signals. Their underlying technology can be based on measurements of either the reflected signal's transit time or its frequency shift. Radars can be designed to provide either the distance to a detected object or the velocity of that object, and advanced signal processing can refine the detection process further. Axis radars are frequency-modulated continuous wave (FMCW) radars, a type of radar that can determine both distance and speed. They measure radial velocities (the object's velocity component pointing to or from the radar) and use it to calculate actual velocities.

3.2 RCS (radar cross section)

The radar visibility of an object is determined by its radar cross section (RCS). This is a numerical value which can be calculated from information about the object's size, shape, and material, and it ultimately determines how large the object appears to a radar. The RCS for a human typically varies between 0.1 m^2 and 1 m^2 – however, this is also the typical RCS of a crushed can, which is physically much smaller but more visible for a radar. Note that even though RCS is measured in m^2, it doesn't correspond to a real area, but is a hypothetical equivalent.

Table 3.1 Typical radar cross sections.

Object	**Radar cross section**
Insect	0.00001 m^2
Bird	0.01 m^2
Human	0.1 – 1 m^2
Crushed metal can	0.1 – 1 m^2

4 Why use radar in surveillance?

Radars provide surveillance based on a completely different technology compared to, for example, visual cameras. Radars can be integrated into a security system with visual cameras, thermal cameras, horn speakers, and PIR (passive infrared) motion detectors, or be used standalone. Standalone use, or when complemented with audio devices, allows a non-visual type of surveillance that safeguards privacy.

4.1 Reliable in low-visibility conditions

Being blind to visual impressions, a radar isn't affected by visibility-impairing weather phenomena, for example, fog. Radar also works well in difficult or low light, such as intense backlight or even complete darkness. Under such conditions, radar can be a very valuable complement to video surveillance. While thermal cameras with analytics would also do the job, radar provides more object information at a lower cost and enables detection in a wider area.

4.2 Low false alarm rate

In surveillance, it's essential to limit the number of false alarms while not missing any real incidents. For instance, with a direct alarm to a security guard, it's important to have a very low rate of false alarms. If there are too many false alarms, the guard might lose faith in the system and end up dismissing a real alarm.

Alarms from different types of motion detectors or video analytics are often set up to trigger video recordings, to trigger prerecorded audio messages to deter unwanted activity or to directly alert a control room operator. With a high rate of false alarms for video recording, a lot of video will be recorded. This can be a problem if there isn't enough storage to keep all the recordings or if searching through all the alarm-triggered recordings requires too much resources. With a high rate of false alarms of prerecorded audio, you risk reducing the deterrence factor significantly.

A radar can eliminate or minimize false alarms, depending on their causes:

- **Visual effects.** Video motion detectors register motion based on a set amount of pixel changes in the surveillance scene. When a high enough number of pixels look different than before, the detector interprets this as motion. However, if you only look at pixel changes, you will get many alarms that are caused by purely visual phenomena. Typical examples are moving shadows or light beams. A radar will ignore such visual effects due to their lack of a radar cross section, and only detect movement of physical objects.

- **Bad weather.** Rain and snow can seriously impair the sight of a detector based on video, while radar signals are less affected.
- **Insects or rain drops.** With video motion detection, very small objects can cause false alarms if located very close to the camera. Rain drops and insects on the camera lens are typical examples. Insects can especially be a problem when video surveillance is accompanied by IR lighting for night vision because the insects are drawn to the light. Radars can be designed to ignore objects that are very close to the device, thereby removing this source of false alarms. With video, there is no such possibility.

4.3 Integrated analytics

With Axis radars, there's no need for additional analytics. The detection, tracking, and classification of objects are all integrated in the radar device.

4.4 Surveillance with privacy

Surveillance cameras can be perceived to interfere with personal privacy. To install them you might need permits from authorities or personal consent from everyone caught on video. In some locations, non-visual radar detection is a better option. For increased protection you can combine the radar with, for example, a network speaker that plays deterring audio messages when the radar triggers it.

5 Axis radars

Axis radars can be used as stand-alone detectors but also together with a camera that provides a visual view of the scene. Axis radars are recommended in outdoor installations where they can improve detection in challenging conditions and minimize false alarms. Owing to their advanced tracking algorithms and the positioning and speed information they provide, the radars can also add new features to the security system.

Axis radars are intended for monitoring open areas. This can typically be fenced-off areas such as industrial properties or roofs, or parking lots where no activity is expected after hours.

5.1 General features and capabilities

Axis radars share many features with Axis cameras. For example, a radar can be treated like a camera in the security system. It's compatible with major video management systems (VMS) and common video hosting systems. Just like Axis cameras, Axis radars support Axis open VAPIX® interface enabling integration on different platforms.

Also like Axis cameras, Axis radars can be set to trigger different actions upon detection. For deterrence, for example, they can use the integrated relay to switch on LED floodlights, play audio on a horn speaker, or start a video recording and send alerts to security personnel. The classification functionality can ensure that this rule is only applied when a detected object has been categorized as, for example, a human or a vehicle.

To make it easier to see where objects are moving, you can upload a reference map, for example a ground plan or an aerial photo, that shows the area covered by the radar.

Figure 2. Screenshot of Axis radar user interface with reference image of a scene.

The radar provides continuously updated positioning information. This is done through an open metadata stream, compliant with the ONVIF specifications where radar-specific information such as position and velocity has been added as an extension. Third-party developers can use this information for creating their own applications for, for example, crossline detection or speed monitoring. It is also possible to add the radar's geolocation and bearing to help visualize the detections in real time in an overview image or a map.

Due to its information about speed and distance the radar also provides capabilities to filter based on speed and based on how an object passes through an area.

5.2 Typical use

Radars are often combined with other devices for optimized detection or deterrence. Common radar use includes:

- **Detection and visual verification with radar and camera.** To efficiently identify the cause of an alarm, or to enable identification of individuals, the scene can also be monitored by a video camera. For this use case, a radar-video fusion camera could be used instead to provide even better detection, classification, and visualization.
- **PTZ autotracking.** Axis radars can be used for PTZ (pan-tilt-zoom) autotracking. Detection by the radar will then automatically trigger a connected PTZ camera to pinpoint and follow the detected object and provide visual details. The autotracking functionality is possible because the radar provides the exact geographical location of the object. Axis offers both edge-based and server-based autotracking. With the server-based feature, you can combine several PTZ cameras and radars, placed in different locations.

- **Perimeter protection with radar and thermal camera.** Protection of a restricted area can be provided by thermal cameras at the perimeter, complemented with radars to keep track of intruders within the restricted zone. This setup provides a cost-efficient combination of a thermal camera's narrow but long detection area, and a radar's wide detection area.
- **Detection and deterrence with maintained privacy.** In an installation with a radar and a network horn speaker, intruders detected by the radar can be efficiently deterred by an audio message.
- **Traffic speed and driver feedback.** A radar can be used to detect speeding vehicles. Check the user manual for configuration and maximum speed. You can connect a radar to a digital speed sign to display the speed of passing vehicles. Such speed signs provide feedback to drivers and are highly effective at getting drivers to slow down.
- **Traffic statistics.** A radar can count vehicles and gather traffic statistics about vehicle speeds and vehicle direction. With a camera and AXIS Speed Monitor, you can visualize the statistics for actionable insights into conditions and safety on the monitored road.

5.3 Area monitoring and road monitoring

Axis radars are intended for monitoring open areas. You can use Axis radars either for area monitoring or road monitoring. They have two profiles to optimize the performance for each one of the scenarios.

The **area monitoring profile** is optimized for objects moving at low speeds. This profile allows you to detect whether an object is human, vehicle, or unknown. You can set a rule to trigger actions when any of these objects is detected.

The **road monitoring profile** is optimized for tracking vehicles moving at high speeds on suburban roads and highways.

See each radar's user manual for details about the profiles and their respective speed specifications.

5.4 Scenarios and exclude zones

To determine where to detect motion, you can add multiple zones. Different zones can be used to trigger different actions. There are two types of zones:

A **scenario** (previously called include zone) is an area in which moving objects will trigger rules. The default scenario matches the entire area covered by the radar. You can add scenarios if you want to create different rules for different parts of the scene. When you add a scenario you can choose if you want to trigger on objects moving in an area or on objects crossing one, or two, lines.

An **exclude zone** is an area in which moving objects will be ignored. You can use exclude zones if there are areas inside a scenario that trigger a lot of unwanted alarms.

5.4.1 Handling unwanted reflections with exclude zones

Objects made of reflective materials such as metal can disturb the radar's performance. The reflections can cause false detections, which can be difficult to separate from real detections.

Unwanted detections can also occur in areas with a lot of moving objects, for example a busy street, or an area with trees or bushes with swaying foliage.

You can avoid unwanted detections by adding exclude zones in the radar's web interface. The radar will ignore all moving objects within the defined exclude zone.

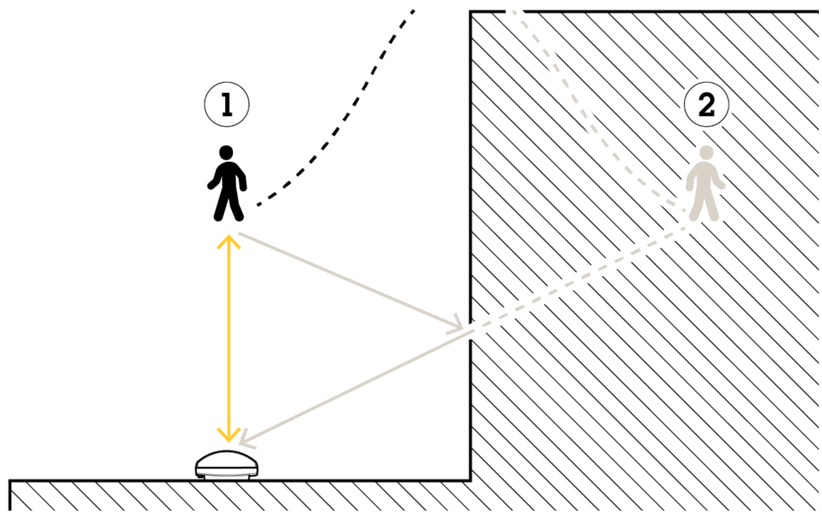

Figure 3. With walls or similar objects in the radar's range, false detections (2) caused by reflection can be difficult to separate from real detections (1). In this example, you could minimize the issue by adding an exclude zone around the wall.

5.5 Detection range and use of multiple radars

The detection range differs depending on the type of object to be detected. It also depends on the scene topography and the radar's mounting height and tilt. You can install multiple radars to cover areas that are larger than each radar's specified detection area.

To avoid electromagnetic interference you shouldn't exceed the maximum allowed number of neighboring radars within the same coexistence area. Interference can affect radar performance negatively. Interference issues increase with the number of radars within the same coexistence area but depend also on the surroundings and the radar's direction towards fences, buildings, or neighboring radars. If you exceed the maximum allowed number of neighboring radars within the same coexistence area, you should direct neighboring radars away from each other. Axis radars also have a coexistence option that you can activate to minimize interference.

See the applicable installation guide and user manual for range specifications and installation advice to achieve maximum coverage and minimal interference with each radar. You can also use AXIS Site Designer to plan radar placement and coverage.

5.6 Tracking and classification

The detection, tracking, and classification of objects are all integrated in the radar, and no additional analytics applications are needed. By measuring the phase shift and frequency shift of the reflected signals, Axis radars obtain data on a moving object's location, speed, direction, and size.

The data is then processed by the radar's advanced signal processing algorithms which track and classify the detected objects. The system groups the reflection data in clusters to represent each object and collects information about how the clusters move over consecutive time frames to form tracks. After applying a mathematical model of motion patterns, "filtering" the data, the algorithm can determine which category the object belongs to, for instance human or vehicle. The classification algorithm, which combines traditional machine learning with deep learning methods, has been trained using a large data set of radar signatures from humans, vehicles, and various animals. No further training is required by the user.

The mathematical model applied can also predict the object location if needed, for instance, if the radar should miss a frame or if the object is occluded for a short period of time. The tracking algorithm thereby makes the radar more robust against noise and faulty measurements.

5.7 Considerations

As with all detection technologies, there are circumstances where the performance of Axis radars can be less than optimal. Known circumstances include:

- **Swaying stationary objects can cause false detections.** Even though the radar can normally filter out trees, bushes, and flags that sway with the wind, the filtering algorithm can be insufficient in very windy weather or sudden gusts of wind. If this is a problem, you can exclude entire zones instead.
- **Vegetation can limit the detection efficiency of very slow-moving objects.** For a given range and velocity, the radar can only detect one object. That means that a group of slowly swaying trees at, for example, 50 m distance in one direction, could block the detection of a slowly moving person at 50 m distance in another direction.
- **A busy environment can cause false detections.** In scenes with a multitude of reflecting objects, such as vehicles and buildings, the multiple reflections of the radar signal could cause false detections.
- **Two (or more) moving persons or objects can be incorrectly classified as one person or object.** The radar typically requires objects to be at least 3 m (10 ft) apart to be distinguished as separate objects.
- **For traffic use cases, check the speed limit for the device and profile you're using.** The tracking algorithms are designed to handle speeds below the maximum speeds listed in the datasheet. Objects that go faster might be missed or be detected with the wrong angle.

5.8 EMF safety

Manufacturers of radio equipment that emit electromagnetic fields (EMF) are required to adhere to stringent international standards and regulations to ensure the safety of their products. This includes Axis radars, which operate in the 24 GHz or 60 GHz frequency bands. Although devices in these bands don't require a license, Axis uses evaluations performed by independent test and certification service providers to ensure compliance with local and international regulations regarding human exposure to electromagnetic fields.

Exposure limits for electromagnetic fields are established, based on extensive medical research, to ensure the safe operation of EMF-emitting devices. Many countries adopt the guidelines set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP)[1], while the United States follows similar limits enforced by the Federal Communications Commission (FCC)[2]. These limits are conservatively set, with a large safety margin, significantly below the levels at which negative health impacts have been observed.

Axis radars operate within these safety limits. The emissions are considerably lower than the prescribed reference levels during normal operation, allowing for the safe use of multiple radars on the same site without concern for radiation safety.

Axis radars transmit power well below 100 mW, comparable to the power output of a standard Wi-Fi® router. Power density follows the inverse-square law meaning that it rapidly decreases with increased distance from the source. Consequently, at a short distance of just a few centimeters, the power density of an Axis radar is already far below the EMF exposure limits.

Axis recommends maintaining a distance of at least 20 cm (~7.9 inches) from the radar for optimal safety. At this distance, the power density is only 0.2 W/m², which is well beneath the public exposure limit of 10 W/m² as set by both ICNIRP and the FCC. This recommendation ensures additional safety and peace of mind for persons in proximity to the radar.

[1] ICNIRP Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz), *https://www.icnirp.org/cms/upload/publications/ICNIRPrfgdl2020.pdf*

[2] FCC Guidelines for Evaluating the Environmental Effects of Radiofrequency Radiation, *https://www.fcc.gov/document/guidelines-evaluating-environmental-effects-radiofrequency*

6 Surveillance technology comparison

There is no single technology that is ideal for all installations. The table provides a comparison between surveillance technologies, including radar, taking multiple factors into account.

Table 6.1 Product comparison within detection and area protection.

	Axis radar	Surveillance camera with motion detection	Thermal camera with analytics
Range/area	Medium/wide	Short/wide	Long/narrow
Requires lighting	No	Yes	No
False alarm rate	Low	High	Low
Cost	Medium	Low	High
Object information	Detection, position, GPS coordinates, speed, distance, movement angle	Detection, recognition, identification	Detection, recognition

As the comparison shows, radar surveillance provides a different type of object information, including position and speed, compared to the other technologies. However, for optimal surveillance it is recommended to combine more than one technology and let them complement each other, since all technologies have their unique strengths and limitations.

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About Axis Communications

Axis enables a smarter and safer world by creating solutions for improving security and business performance. As a network technology company and industry leader, Axis offers solutions in video surveillance, access control, intercom, and audio systems. They are enhanced by intelligent analytics applications and supported by high-quality training.

Axis has around 4,000 dedicated employees in over 50 countries and collaborates with technology and system integration partners worldwide to deliver customer solutions. Axis was founded in 1984, and the headquarters are in Lund, Sweden

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