WHITE PAPER

Radar in surveillance

Technological background and performance considerations

June 2023

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1 Summary

Radar is an established detection technology based on radio waves. It is increasingly used in consumer products because modern radar devices can be small and chip based.

Being based on a non-visual technology, radar has a lot to offer in surveillance. Security radar works well in many situations where other surveillance technologies may fail, such as in poor lighting, darkness, and fog. Radar is also stable in many situations where video surveillance with analytics software are likely to create false alarms, for example, when there are moving shadows or lights in the scene, in bad weather, or when there are raindrops or insects on the device. Radar also has the benefit of providing surveillance that maintains privacy because people can't be identified from the radar information.

Security radar from Axis can be used on its own, for example in environments where cameras aren't allowed due to privacy concerns. But radar is primarily integrated into a security system with video and audio products. Just like Axis cameras, Axis security radars are compatible with major video management systems (VMS) and can be set up to trigger a range of actions upon detection.

With Axis radar, no additional analytics applications are needed, since detection, tracking, and classification of objects are all integrated in the radar device. A deep learning classifier algorithm distinguishes the type of detected object, for example a human or a vehicle. Axis has used both machine learning and deep learning to develop the algorithm.

Radar devices are commonly combined with visual cameras for identification of individuals. This is especially effective with PTZ (pan-tilt-zoom) cameras, which can track and identify persons or vehicles based on their exact geographical position provided by the radar. Radars are also often used together with thermal cameras, where the radar devices' wide area detection combines well with thermal cameras' narrow but long detection area. Radar and audio are also a good combination where visual identification either isn't allowed or isn't prioritized. A deterring audio message may very well stop an intruder detected by the radar.

A comparison table in the last section of this paper lists the differences and similarities between security radar, visual cameras, and thermal cameras. A combination of technologies is often a good choice, since they all have their 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 may need to consider before installing a security radar device, 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 device 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.

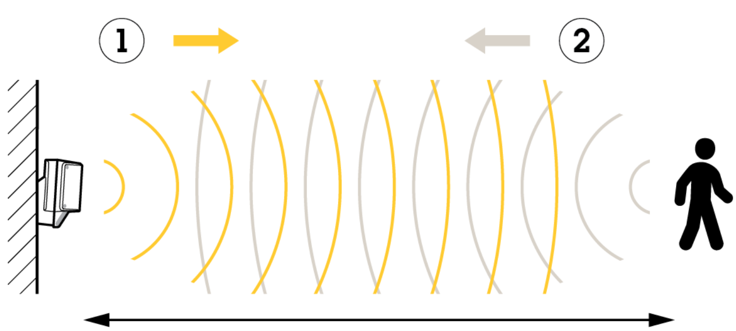

Figure 1. The general principle of radar: a signal emitted from the radar is reflected upon hitting an object.

While employing the same general principle, radars can be constructed to work with either short radio pulses or continuous signals. Their underlying technology may be based on measurements of either the reflected signal's transit time or its frequency shift. Radars may 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. Radar products from Axis 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 device) 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

3.3 EMF safety

Manufacturers of radio equipment that emits electromagnetic fields (EMF) must ensure that their products comply with applicable exposure limits, as formulated in international standards and regulations. Radar products from Axis are defined as short-range devices (SRD) with limited electromagnetic power and range. They fulfill the requirements regarding EMF safety. Please see the product's declaration of conformity for details.

4 Why use radar in surveillance?

Security radar provides surveillance based on a completely different technology compared to, for example, visual cameras. It 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 may cause less privacy issues than traditional video surveillance.

4.1 Reliable in low-visibility conditions

Being blind to visual impressions, a radar device 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 may be problematic, either because there isn't enough storage to keep all the recordings, or, if there is enough storage, a forensic search through all alarm-triggered recordings may require more resources than the system owner can afford. With a high rate of false alarms of prerecorded audio, you risk to reduce the deterrence significantly.

A security 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 security 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.
- **Tiny objects on the device.** With video motion detection, tiny objects can cause false alarms if located very close to the camera. Rain drops and insects on the camera lens are typical examples. Insects may 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 security 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 may be a sensitive matter, and security cameras are often perceived to interfere with personal privacy. Installation of cameras may require permits from authorities or personal consent from everyone caught on video, and in some locations, a camera is not an option. The non-visual detection provided by radar often provides sufficient protection in these cases. This is especially true if the radar device is complemented by, for example, a network speaker which can send out deterring audio messages upon detection.

5 Axis security radars

5.1 A complement to Axis cameras

Axis security radars can be used as stand-alone detectors but may serve their purpose even better when complemented by a camera that also provides a visual view of the scene. Axis radar devices 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 radar devices can also add new features to the security system.

In order to facilitate a visual interpretation of the scene, a reference image can be uploaded and combined with the radar view.

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

Axis radar devices share many features with Axis cameras. For example, a radar device 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 security radars support Axis open VAPIX® interface enabling integration on different platforms. And, also like Axis cameras, Axis radar devices can be set to trigger different actions upon detection. For deterrence purposes, for example, it 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.

The radar device 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 device's geolocation and bearing to help visualize the detections in real time in an overview image or a map.

5.2 Handling unwanted reflections with exclude zones

Objects of radar-reflective materials, such as metal roofs, fences, vehicles, and even brick walls may disturb the radar's performance. They may create reflections which cause apparent detections that can be difficult to separate from real detections.

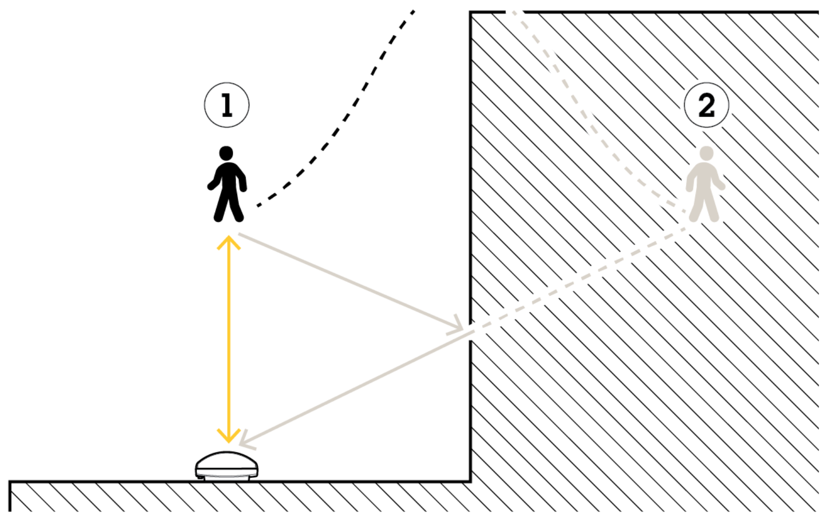

Figure 3. With walls or similar objects in the radar's range, apparent detections (2) caused by reflections may be difficult to separate from real detections (1). In this example, an exclude zone around the wall could minimize the problem.

Unwanted reflections within the detection range can be avoided by use of *exclude zones*, which can be drawn in the radar device's user interface.

Detection and tracking of objects take place continuously within the whole detection range. However, owing to its filtering functionality, the radar device will trigger actions only on objects detected within an include zone. The filter can also be set to ignore specific object types, and, for example, only trigger on vehicles or objects that have been tracked for a certain amount of time.

There will be no triggers in areas outside of the include zones. Nonetheless, exclude zones can be placed within an include zone. This can be a tool for avoiding triggers in, for example, a particularly busy area with objects that may cause false alarms, such as swaying bushes and trees. Data from the immediate proximity of the radar device, however, is disregarded by default, which means that neither water drops nor insects on the radar's surface will cause any false alarms.

It can be useful to add exclude zones outside of the include zones. If done, the radar will ignore detections there and use the processing power where it's interesting.

5.3 Detection range

Compared to radar used in air traffic control and weather forecasting, Axis security radars are short-range devices. The detection range differs depending on the type of object to be detected, but also on the scene topography and the device's mounting height and tilt. See the applicable installation guide for range specifications and installation advice.

For coverage of a larger area than the specified detection area, it is possible to use multiple radars. However, if the maximum allowed number of neighboring radars within the same coexistence area is exceeded, the radars may interfere electromagnetically with each other. Since the radio waves continue beyond the detection area, one radar may, in that case, cause interference even when placed beyond another radar's detection area.

In case of interference, the detection range becomes shorter, the radar may fail to classify objects correctly, and false alarms may occur. The probability and severity of these issues increase with the number of radars within the same coexistence area but also depend on the environment and the radar's direction towards fences, buildings, or neighboring radars. If the maximum allowed number of neighboring radars within the same coexistence area is exceeded, it is recommended to direct neighboring radars away from each other. Axis radars also have a coexistence option that can be activated to minimize interference.

5.4 Tracking and classification

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

The data is then processed by the device'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 device more robust against noise and faulty measurements.

5.5 Installation considerations

Axis radar devices 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.

For optimal detection and classification performance, Axis radar devices should be installed 3.5 m (11 ft) above ground, on a rigid pole, truss, or wall.

If several radars are required in an installation, they need to be placed in a way that minimizes interference. The number of neighboring radars within the same coexistence zone should be kept down and not exceed the stated maximum allowed number. If there are more than three radars in the same coexistence zone, the radars should be added to groups in the web interface to avoid interference and improve performance.

To cover the area around a building, for example, radars can be placed on the walls of the building, as long as the number of devices in the same coexistence zone does not exceed the limit. To cover an area such as a football field, where it is not possible to place radars in the middle, radars can be placed around the field, facing each other. The distance between the radars must be larger than the stated minimum distance and the number of radars in the same coexistence zone cannot exceed the limit.

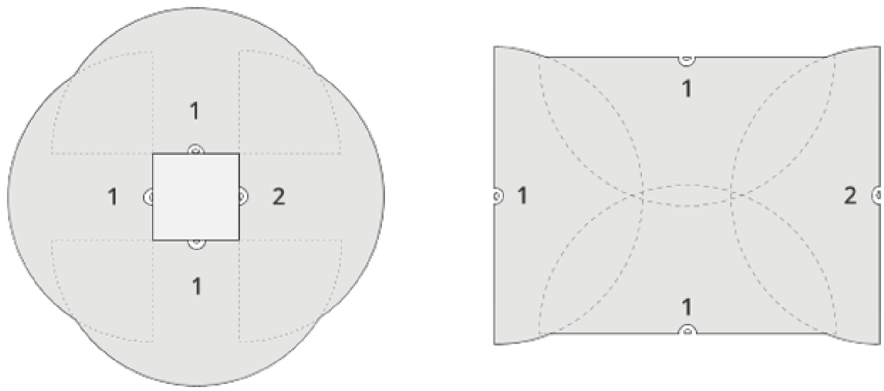

Figure 4. Radars placed on the walls of a building to cover the surrounding area, and radars placed to cover a field (views from above). The numbers indicate an example of how you can add radars in groups of three for optimal performance when you have more than three radars (but not more than the maximum stated number of radars) in the same coexistence zone.

To create a virtual fence, radars can be placed side by side. Check the user manual for recommended spacing and configuration. To cover a large open area, two radars may be placed back to back on a pole.

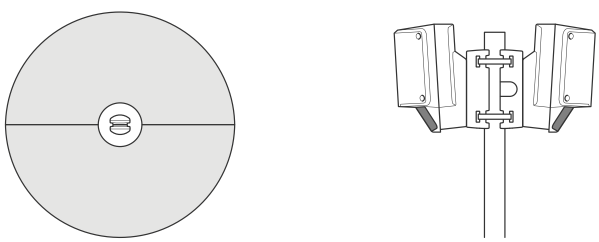

Figure 5. Radars installed back to back on a pole. View from above (left) and from the side (right).

5.6 Common use cases

Radar is often used together with other surveillance technologies in order to optimize detection. Typically, radar devices can be combined with:

Fixed camera. A motion detector based exclusively on radar will not provide any visual confirmation. To efficiently identify the cause of an alarm, or to enable identification of individuals, the scene should also be monitored by a video camera.

PTZ camera. Axis security 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 device 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 radar devices, placed in different locations.

Thermal camera. Protection of a restricted area can be provided by use of thermal cameras at the perimeter, complemented with radar devices to keep track of an intruder within the restricted zone. This setup provides a good combination of a thermal camera's narrow but long detection area, and a radar device's wide detection area.

Outdoor speaker. Using a network horn speaker, radar-detected intruders may be efficiently deterred by an audio message.

A standalone security radar can be used to detect speeding vehicles in a low-speed area. Check the user manual for configuration and maximum speed.

5.7 Considerations

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

- **Swaying stationary objects may cause false detections**. Even though the radar device can normally filter out trees, bushes, and flags that move with the wind, the filtering algorithm may be insufficient in very windy weather or sudden gusts of wind. If this is a problem, it may be recommended to exclude entire zones instead.
- **Vegetation may limit the detection efficiency of very slow-moving objects.** For a given range and velocity, the radar device can only detect one object. That means that a group of trees at, for example, 50 m distance in one direction, swaying slowly in the wind, may block the detection of a human moving slowly at 50 m distance in another direction.
- **A busy environment may cause false detections.** In scenes with a multitude of reflecting objects, such as vehicles and buildings, the multiple reflections of the radar signal may cause false detections.
- **Two, or several, moving persons or objects may be incorrectly classified as one person or object.** The radar device typically requires objects to be at least 3 m (10 ft) apart to be distinguished as separate objects.
- **Axis security radars can be used for traffic use cases in either of the two profiles: area monitoring profile or road monitoring profile.** The tracking algorithms are designed to handle speeds below the maximum speeds listed in the product datasheet. Objects that go faster than the maximum speed may either not be detected at all, or be detected with the wrong angle.

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.

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