White Paper

# Stopped Vehicle Detection (SVD)
# Comparison of SVD Technologies

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## Introduction

This document outlines the essential requirements for stopped vehicle detection (SVD). Three major sensor technologies are then evaluated based on their ability to fulfil these essential requirements. Advantages and disadvantages associated with different sensor technologies are described so end-users can make an informed judgment about the most appropriate equipment to meet the needs of their SVD application.

## Essential Requirements for Detecting Stopped Vehicles

The primary requirement is for a sensor that can detect and report the precise location of an obstruction that is blocking a road and is likely to cause an accident.

High detection probability is required to ensure incidents will not be missed, as well as a low false alarm rate to prevent nuisance alarms that reduce trust in the sensor.

Adverse weather must not seriously degrade performance and despite roadside installation in harsh environments, reliability must remain high.

The sensor size, weight, power and networking requirements must be suitable for mounting on remote roadside poles and gantries.

Equipment must comply with all relevant safety and conformance tests. It is desirable for the sensor to require minimal maintenance to avoid unplanned road closures or downtime.

Although some sensors may exceed these basic requirements, the additional features are “nice to have” rather than essential. For example, the ability to determine the make, model or colour of a vehicle is of little consequence.

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# Video Analytics

**Video analytic systems use computer software to analyse video footage to identify the objects within view. The main points are summarised below:**

**Relatively low-cost video cameras can be used.**

**Live footage can be viewed by operator to confirm detection.**

**Cameras can zoom to give very high resolution (albeit with corresponding decrease in the field-of-view).**

**Video cameras are compact, lightweight and quick to install, but fixed cameras may need careful alignment on site. Heavier, more expensive pan/tilt/zoom (PTZ) cameras may be aligned remotely.**

**Good illumination is essential and artificial illumination (either visible or infrared) is required at night.**

**Cameras must avoid direct exposure to high intensity lighting or direct bright sunlight if it blinds the sensor, therefore a high number of cameras may be required to implement a sufficiently robust and reliable system.**

**Processing is typically performed on a remote server; so high network bandwidth is needed. The alternative is cameras with built-in analytics, however these cost more than a "dumb" camera and may have higher failure rate due to added complexity.**

**Video analytics cannot directly measure distance, so could be confused by forced perspective such as small/close objects that may resemble large/far objects. This can lead to error in reported location of incident.**

**Video resolution, clarity and dynamic range are degraded by smoke, mist, fog, rain, snow, hail, heat haze, bright sunshine and lack of light.**

**Routine maintenance may be required to clear dirt from the camera lens.**

## Technical Details

**Cameras use visible light, so operating range is limited during poor weather such as fog, heavy rain, mist and snow. Bright sunlight is also a major problem as it dramatically reduces the sensitivity of the camera, blinding it when directly facing the sun. This typically occurs when the rising or setting sun is low in the sky. To mitigate this problem additional cameras are needed so they can point in opposite directions. There must also be adequate illumination for analytics to function correctly at night and sufficient overlap of cameras to cope with degraded operating range during adverse weather.**

**Video analytics makes use of Deep Neural Networks (DNNs) to identify objects. DNNs are very different to traditional procedural processing techniques and instead use a simple form of artificial intelligence (AI) that is inspired by animal brain structures.**

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For DNNs to function at all they must first be "trained" using known reference data. In the case of video analytics, training would use input images of objects along with corresponding descriptions, for example: car, truck, motorbike, human, animal, tree, etc.

To ensure the analytics will be accurate there must be sufficient data to suit the amount of variation that is expected in the application. In a highly controlled environment such as a factory, video analytics could inspect a production line checking objects for defects. In this case the amount of training might be reasonably low as there is unlikely to be significant variation in objects that have been manufactured correctly.

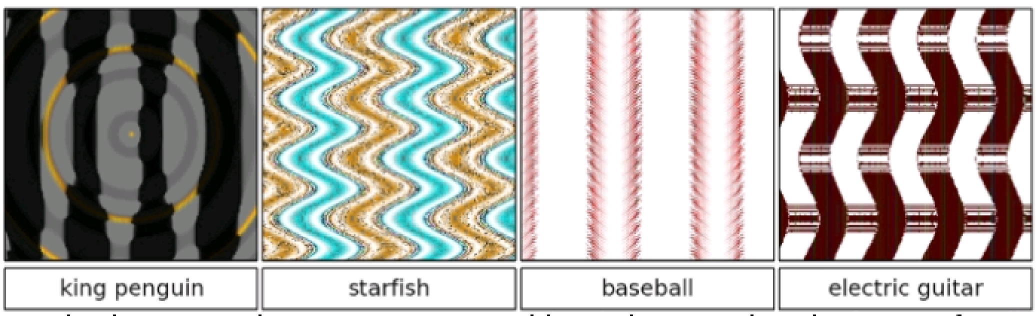
Outdoor applications need significantly higher quantity of training data to cope with changes due to weather and sunlight. When the objects have more freedom to move the training must account for different orientations and varying degrees of obscuration by other objects. If, for example, the system is designed to detect cars then it must be trained with images of different types of cars taken from many different angles.

## Performance Issues

DNNs often provide start-of-the-art results for most tasks. Unfortunately they are also vulnerable to subtle changes in the input data that can cause gross misclassification of objects in such a way that seem incredulous to humans. [1]

For example, studies have shown that simple stickers or graffiti can completely change the result from a DNN. The image shows the placement of four small stickers on a stop sign that resulted in it being mistaken for a 45 MPH speed limit sign. [2]

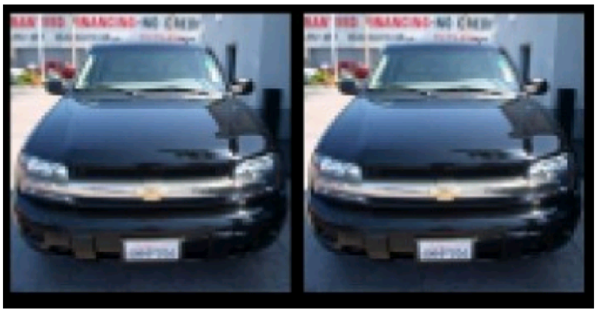

DNN-based systems often have strange behaviours and can completely misidentify objects yet still claim with very high confidence that the classification is correct. Another study [3] showed various situations with gross misclassifications. An example is shown below:




Evolved images that are unrecognizable to humans, but that state-of-the-art DNNs trained on ImageNet believe with ≥ 99.6% certainty to be a familiar object.

**Although this study was a deliberate attempt to subvert the DNN, it still indicates that the underlying technique is fundamentally different to human vision; DNNs simply do not see the world as we do. For example during heavy fog a human may struggle to discern an object but would understand the context of the situation and make much better guesses than a DNN with the same visual input.**

**DNNs are very sensitive to subtle changes in images that are invisible to the human eye. A study [4] deliberately introduced very minor pixel differences to alter the image classification between two otherwise identical images. Shown below, the left image was identified correctly as a car, but the right image was unrecognisable by the DNN. The actual differences are extremely subtle and impossible to discern by eye.**



**Other research [5] has revealed that the output of DNNs can be altered by modification to a single pixel, albeit on relatively low-resolution source images. This raises concerns about dead or stuck pixels on a camera sensor that may degrade detection probability. Larger dust or dirt on the lens is likely to also cause major problems.**

**Motorway environments have many situations that would challenge a video analytic system, such as car transporter lorries, tow trucks, and bicycles being carried on cars. Computers still only have very superficial "intelligence" and struggle in situations where deeper insight is required.**

# Lidar

Lidar stands for light detection and ranging. It is used to measure the range of surrounding objects by emitting laser light and measuring how long it takes for the reflected light to return to the lidar sensor. The main points are summarised below:

Lidar can operate in total darkness.

Resolution is very fine and fast scan rates are possible.

Direct measure of object speed is possible due to the Doppler effect.

Performance is excellent in fine weather or when used indoors but is fundamentally limited to very short ranges outdoors because it is degraded by rain and fog.

Lidar struggles due to raindrop absorption and water vapour scattering the laser.

Large numbers of lidars are required to achieve total road coverage.

Lidar is vulnerable to dust or dirt on the sensor and may require routine maintenance.

## Technical & Performance Details

Lidar uses visible, ultraviolet or infrared light emitted in narrow beams by a laser. The two most common Lidar wavelengths are 905nm and 1550nm [9]. Since Lidar generates the stimulus signal from a laser it does not rely on external light sources and can operate in complete darkness. The generated laser beam is very narrow and its direction can be controlled with high precision, therefore angular resolution is excellent, typically less than 1 degree; therefore lidar can resolve fine details.

All opaque and translucent objects reflect the laser beam to some extent. Lidar equipment specifications typically state the maximum detection range for objects with a certain reflectivity. This reflectivity percentage determines how much of the incident power is returned as reflected power. Reflection takes two forms: specular (like a mirror) or diffuse, which scatters in many directions. Different materials have different reflectivity as well as different ratios of specular and diffuse reflection.

Highly polished specular surfaces, such as glass, can cause problems. Vehicle windscreens exhibit very low reflectivity when the angle of incidence is off-axis because most of the reflected light is angled away from the lidar sensor.

When used outdoors, weather degrades lidar performance. The effect of fog is due to the water content: aerosols scatter light and water droplets absorb light. Research using a 905nm Velodyne HDL-64E lidar showed that fog reduced the laser pulse dramatically, resulting in a low contrast image that made it difficult to detect objects. [7]

A study in 2019 showed that state-of-the-art 905nm lidars were degraded significantly in fog such that when the visual range was 40m the lidar could only measure to 25m at most, even when the target had high reflectivity (90%). It would not be possible to overcome the problem by increasing brightness, as it would present a blinding hazard to anyone not wearing eye protection. [8]

In the case of 1550nm lasers it is possible to increase the brightness because less of the light can reach the eye's delicate retina. In clear weather there is an advantage, however water absorption is around 100 times higher at 1550nm so the effects of rain and fog are substantially worse, mitigating any improvement over 905nm when used outdoors. [9]

Large raindrops also degrade lidar performance. Although the rapid measurement speed means that raindrops are effectively frozen in place during the measurement, they still affect the number of measured points as they attenuate the laser beam. A study from 2020 observed a significant reduction in points at the farther distances from no rain to 10mm/h to 50mm/h, and a significant drop of the detected points as the rainfall intensity increases. [10] For reference, rainfall up to 2mm/h is considered as a light shower, 10mm/h a moderate shower and above that a heavy shower. Rainstorms potentially reach 100 mm/h.

Opaque objects block laser beams, so dirt, dust or grime over the sensor can seriously degrade performance.

The image above shows typical road scene mapped by a lidar sensor during clear weather. Pixel brightness corresponds to the reflectivity of the surface.

# Radar

Radar stands for radio detection and ranging. It is used to measure the range of surrounding objects by emitting radio waves and measuring how long it takes for the reflected waves to return to the radar sensor. The main points are summarised below:

Radar has long-range operation with virtually no degradation due to weather.

Wet roads and water spray from vehicles has negligible effect on performance.

Radar operates in any ambient light level even total darkness.

Radar can see through thick smoke and fire.

Direct measure of object speed is possible due to the Doppler effect.

Resolution is typically fairly coarse compared to other technologies and beam divergence causes angular resolution to decreases as range increases.

Radar systems can be confused if signals reflect from multiple other objects, or if stray signals are seen by the antenna sidelobes rather than main beam.

Interference from nearby transmitters and other radars may degrade performance.

## Technical & Performance Details

Radar uses radio waves rather than visible light or lasers; therefore ambient light levels have no affect on performance whatsoever. There is a vast frequency spectrum of radio waves but the choice of operating frequency largely depends on the application and the local regulations. For detecting vehicles and ground objects, radars typically utilise microwave (0.3GHz – 30GHz) or millimetre waves (30GHz and higher) as fairly small, narrow field-of-view antennas can be fabricated.

Adverse weather has minimal influence on radar performance. Fog and smoke are essentially transparent to radar sensors and the effect of rain can be negated using well-known techniques.

Radars measure all objects including surrounding ground, vegetation, buildings, lamp posts, gantries, signs and debris. Reflected signals from unwanted objects are collectively known as clutter. For a sufficiently low false alarm rate, radar must be able to resolve the wanted objects from the clutter in the surrounding environment. Making the beam as narrow as possible and using digital techniques to ignore fixed objects reduces the effect of clutter.

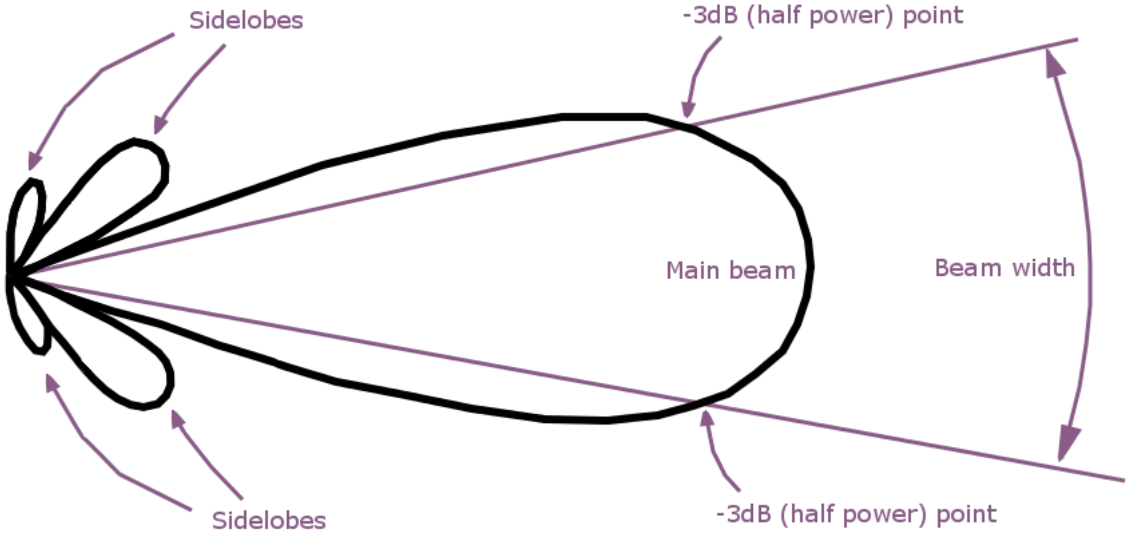
Since radar utilises the reflection of radio waves off solid objects, secondary reflections from other large objects may also cause ghost objects to be detected at incorrect locations. This can be especially problematic in road environments where lorries carrying shipping containers act as large reflectors.

Within radars, antennas focus the radio waves into a narrow beam. Beam width in degrees is constant, so as range increases the actual width of the beam has a corresponding increase that decreases measurement resolution. Beam width ultimately determines the maximum effective range of the radar, as beyond a certain range objects and clutter will be indistinguishable.

Due to fabrication imperfections all antennas have sidelobes, which are signals that radiate at unwanted angles. When a large object is seen in the direction of a sidelobe the radar may incorrectly report that the object lies in the direction of the main beam. This problem is especially obvious when large lorries are detected in sidelobes as the returned signal level may be similar to that of a small car or motorbike within the main beam. Generally, the lower the sidelobes, the better the ability to reject false alarms. Many different techniques are used to reduce sidelobes but ultimately manufacturing tolerances provide a fundamental limit.

To reduce clutter a narrow beam is needed. To halve the beam width, a doubling of either antenna size or operating frequency is required. Operating frequency is typically greater than 10 GHz so equipment size can be fairly compact. The precise operating frequency varies based on the availability, cost and manufacturability of components and the radio regulations that may be applicable. For example as frequency increases antennas can be made smaller but sidelobes may get worse as manufacturing tolerances become more critical, so there are tradeoffs.

The diagram below shows a typical antenna radiation pattern that graphically shows the beam width and sidelobes for an antenna. When drawn against scaled radial lines and concentric circles, the angle and magnitude of the sidelobes, and the main beam shape and width can be evaluated.




To minimise operating costs, license-exempt frequency bands are typically utilised as there are no license fees payable to the national radio regulators. Other equipment may also use license-exempt frequencies so careful choice of frequency band and receiver architecture is required to mitigate the risk of interference. Generally radars are not susceptible to interference from transmitters on other frequency bands as frequency selective hardware filters are fitted as required.

# Conclusion

All three systems have various strengths and weaknesses. Referring back to the essential requirements for SVD, fundamentally if a technology can't operate under all weather conditions then it is not a viable solution. Lidar and video analytics therefore are poorly suited to the application.

Video analytics has inherent weaknesses that are not present in human vision. The robustness of the technology is difficult to prove, especially when faced with a situation where there are many variables, which is typical for roadside usage.

For SVD the video analytic solution would have to cope with vehicles of different shape, size, colour with various bold artwork and logos and partial obscuration that may disguise the shape. The environment presents many variables such as ambient light level ranging from darkness to bright direct sunlight, bright glare from headlights at night, fog, rain, hail, snow, lightning, smoke, heat haze, water spray from road surface and sun glare off wet road surfaces.

While lidar performance is generally excellent indoors, it has severely degraded operation when used outside especially due to rain and water vapour. It may struggle to detect large parts of targets where the reflectivity is low, either due to specular reflections from glass or even black paint, to the extent that pigment manufacturers have recently had to create new paint mixes to help lidar to function [11]. Unfortunately this does not solve the problem with existing vehicles that remain harder to detect.

Both video and lidar systems require regular maintenance to clean dirt and grime from the sensor but radar is able to penetrate typical contaminants and does not require washers or wipers.

In general, radar is fully able to operate in all weather conditions with very minimal changes to performance. Although optical and laser systems have much finer resolution than radar, the resolution of radar is still sufficient to meet the essential requirements.

Common to all three systems is the need to have direct line-of-sight between sensor and object, therefore regardless of sensor type, it must be mounted in such a way that obscuration is avoided, usually by being higher than tall vehicles and with a wide vertical field of view to minimised any blind spot underneath the sensor. Therefore the implementation of the technology is just as important as it has a direct impact on system performance.

Although radars need to overcome multiple reflections, sidelobes and clutter, techniques exist to minimise these effects so they have negligible effect on the ability to meet the essential requirements for SVD.

Furthermore, in tunnel environments radar is able to see through smoke and unlike lidar or video analytics is able to utilise signals reflected from solid tunnel walls to overcome any obscuration issues that could affect optical and laser systems within tight tunnel bores.

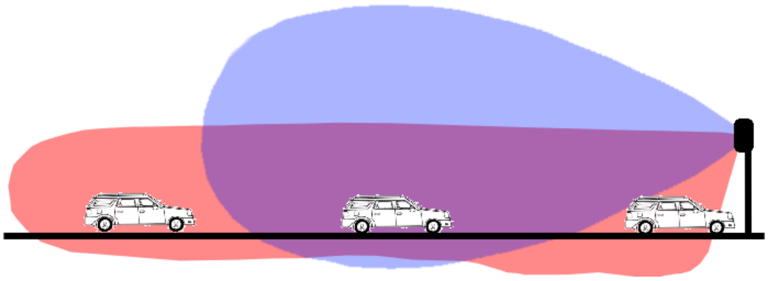
## About SVR-500

SVR-500 is the Ogier Electronics radar solution optimised for stopped vehicle detection. It scans up to 500m of road every second, covering all carriageways. This distance corresponds to the typical length of roadway that can be observed before curvature or other line-of-sight issues start to cause obscuration.

SVR-500 uses 24 GHz microwave radar technology to mitigate the environmental factors that degrade other technologies, using proven principles that have been refined many years. Radar has a true all-weather capability and SVR-500 has been designed to overcome difficulties that are specific to the SVD application. The field-proven concepts used in the Ogier Electronics Scan-360 series of site security radars have been broadly incorporated in to SVR-500 so the core design is built upon robust foundations with an enviable record of reliability.

SVR-500 does not use DNNs where it is hard to predict how, and why, errors might occur. Instead the processing concept is straightforward and can be understood easily, aiding assessments of system stability and robustness. Application specific procedures and rules designed by a human have been implemented as sequential tests for a microprocessor to undertake. Simple deductive reasoning is used to ignore any ghost detections caused by multiple reflections. If the tests result in contradictory outcomes the ghost object is ignored, avoiding a potential false alarm.

Extensive design effort has resulted in antennas with excellent characteristics that meet the demanding essential requirements: In the azimuth plane, sidelobe levels are very low to reduce the possibility of false alarms and the narrow beam width is sufficient to resolve individual vehicles even at maximum range. In the elevation plane, the fan beam shape eliminates the need for precise tilt adjustment and gives extremely broad coverage, therefore SVR-500 can be mounted very high to see over the top of large vehicles while also having excellent close-in performance being able to detect vehicles almost directly underneath the sensor.



SVR-500 mitigates interference by using dedicated signal processing routines to detect then remove unwanted signals based on recognisable characteristics. Where necessary narrow bandwidth hardware filters are also fitted to block high power TV/radio transmitters and military, airport or marine radars. Extensive trials have shown negligible interference from other equipment, including automotive radar.

SVR-500 is quick to install and simple to configure. To aid operators, SVR-500 can slew PTZ CCTV cameras to point toward the detected incident so control room staff may make a rapid visual assessment to determine the appropriate response.

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