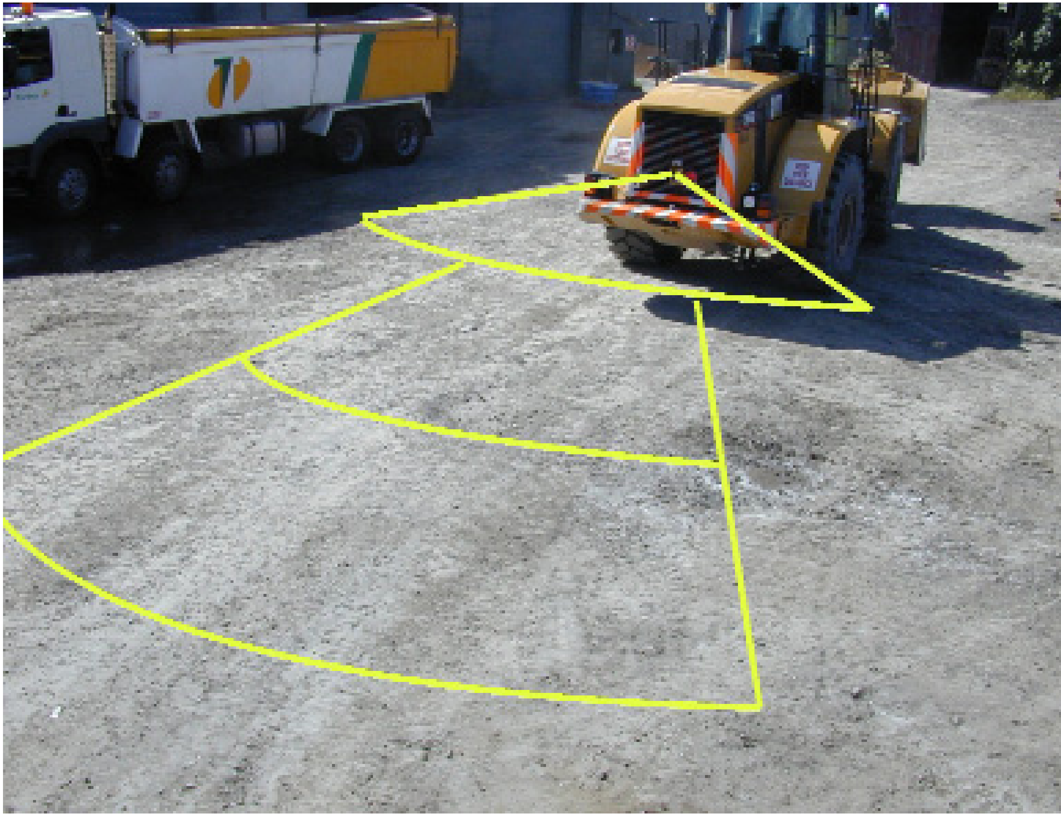

A typical protection zone behind a wheel loader, showing the three stages of warning

Guardian Angel or Back-seat driver?

Warning drivers of collision hazards behind mobile plant

The dangers of mobile plant, especially when reversing, are well known, so how can they be reduced? CCTV is now almost universally fitted but reversing accidents still happen, often because the driver was not looking at the monitor at the right time. So why are sensors not fitted to warn the driver that there is something behind him?

Every supermarket has doors that open automatically and these days every other house appears to have a security light that comes on when someone approaches, so why can't one of these sensors be wired up to an alarm in the cab to remind the driver to check whenever there is something behind him?

The answer is it could, but the system would be in almost constant alarm and the driver would get so fed up he would very soon either ignore or disable the alarm. In this application the problem is not just how to detect people or other objects, but how to restrict the response to those objects which are a genuine hazard.

There are sensors designed to overcome this problem, however the problem is complex and no single system can claim to be the perfect solution. Earthmoving machines work in difficult and varied conditions and not everything in the path of the machine is a hazard. However, by carefully tailoring the response of the sensor, warning systems can improve the safety of mobile plant operations.

International standards

The International Standards Organisation (ISO) has been examining the requirements for hazard-detection and warning devices for off-highway vehicles for some time. It has proved a difficult subject to standardize because, at the current state of the art, there is no satisfactory standard solution for all types of machines operating in the off-highway environment.

A standard is being prepared which is designed to guide the user in the selection of suitable equipment. It covers the suitability of systems for the difficult mechanical and EMC environment endured by equipment installed on mobile plant. It also describes the advantages and disadvantages of the sensor techniques currently available and methods for evaluating the shape and size of the zone in which reliable detection occurs. However, it does not attempt to define the exact shape and size of the detection zone required because it also recognizes that unwanted alarms are a critical factor in the effectiveness of any system. Hazard-detection systems must be part of the total safety assessment and must be tailored to achieve maximum effectiveness in each application.

Reliability

If a hazard-warning system is to achieve the objectives set out in the proposed ISO standard it must be designed to minimize the occasions when warnings relate to objects which do not present a hazard. But it must also continue to detect reliably in all conditions in which mobile plant are expected to operate.

For indoor applications, particularly on autonomous guided vehicles, lasers and ultrasonic sensors have been developed which provide reliable detection of hazards, with the minimum of unwanted alarms, in a well defined zone close to the machine. However, these indoor sensors may have difficulty coping with some outdoor conditions. Although sensors based on these technologies are being developed for outdoor applications, radar has proved to be much more tolerant of typical mobile plant conditions. ➤

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Shape and size of the detection zone

Different types of sensor create the shape of the detection zone in different ways. Lasers typically sweep a narrow beam, taking separate readings at each angle. Ultrasonic systems typically use multiple narrow-beam sensors, while radars typically use a fan-shaped beam which spans the full width of the machine, although they may use more than one beam to achieve the full shape required. All practical systems for this application must measure the distance to each object and relate the alarm to the distance.

The shape required for the detection zone will depend upon a number of factors. In the horizontal plane the shape must anticipate the reversing path of the machine. This is not necessarily a simple rectangle behind the machine, limited to the machine width. Machines often reverse on full lock, so the protection zone may need to extend beyond the width of the machine. If it extends too far, however, it may generate unwanted alarms from objects to the side of the reversing path. Also, in a typical dumptruck installation the sensor will be mounted between the wheels and thus the protection zone may need to be close to the sensor to avoid alarms caused by the wheels.

In the vertical plane the main consideration is the bottom edge of the protection zone, because although damage can be caused to the machine and other equipment by collision with the top of the vehicle, injuries to people are more likely to occur when they are on the ground or in a small vehicle on the ground. Ideally, the protection zone should extend down as close to the ground as possible, but in the typical mobile plant environment a zone that extends closer than 1m from the ground is liable to generate false alarms due to the uneven nature of the ground surface.

The maximum range at which warnings need to be given will depend upon the anticipated reversing speed, the driver's reaction time and the machine's stopping distance. The theoretical stopping distance for a machine capable of travelling at 30km/h in reverse over wet slippery ground where retardation is down to 0.2g, may be as great as 20m. For a machine working in an open area on level ground, a protection zone extending that far would be acceptable, but for a machine working in a more typical mobile plant situation it would be impractical. To have warnings triggered every time something was closer than 20m from the rear of the machine would be intolerable. The maximum distance for the detection zone therefore needs to be selected to suit the working environment and 8–9m is generally more typical.

Relating warnings to machine movement

The warning system must also consider machine movement. If a warning persists when a machine is stationary near to a fixed structure, this will cause considerable irritation to the driver and undermine the value of all warnings. If warnings are only given when the machine is in reverse gear, other factors need consideration.

The detection of reverse gear engagement must be secure. If a CCTV fails to switch on because the reverse switch fails, the failure is obvious to the driver. But if a warning system fails in the same way it is only apparent if the driver is already aware of a hazard which is not detected. Any warning system that relies on reverse gear should therefore have a secure, fail-safe method of monitoring gear selection.

The other factor is the possibility of a person approaching the machine before reverse is selected and being immediately behind the machine when it is selected. With a slow-moving machine and secure detection close to the machine and across the full width, the warning may be adequate at the time of engaging reverse. If, however, any blind spots exist close to the machine or if the machine could injure a person behind it before the warning registers with the driver, leaving all warnings until reverse is engaged could compromise safety.

There may also be situations in forward gear where the driver needs to be aware of a vehicle behind him, ie one which is about to overtake. There may also be instances where a driver, stopped on an uphill slope, may ease a machine back using the brakes, without engaging reverse gear. In these circumstances a loaded dumptruck could easily crush a small vehicle behind it.

Practical experience

Ogden Safety Systems Ltd have been developing reversing protection systems for the quarrying and mining industry for over 20 years. After several years of trials with several sensor technologies, a technique known as FMCW radar was selected as the most suitable. This radar-based system has been further developed over the years but it is still based on the FMCW principle.

A number of alternative radar techniques have been developed for other applications but none offer the same facilities as FMCW for separately sensing multiple low-speed objects and measuring their speed and direction of movement.

The early Ogden systems were all automatic braking systems where the maximum detection distance required for a typical application is 4m. These systems require secure interfacing to the machine transmission to ensure that the brakes cannot be applied when the machine is not in reverse gear. They do not require the radar to sense the direction of movement and a detection zone based on a single, wide arc provides a satisfactory shape for this application.

When demand arose for a system to provide a warning only, it was necessary to develop additional features. Obtaining a reliable interface to the machine transmission is an expensive, specialist part of the installation and therefore a radar which can identify whether an object is approaching or moving away makes a secure system easier to install.

On the automatic braking system, a feature had already been added to provide an audible warning when the machine was not in reverse gear. This relied on monitoring the Doppler effect to avoid constant warnings when the machine was stationary. However, when the size of the protected area was increased to that necessary for a system without automatic braking, drivers complained of unwanted alarms. Some were caused by the increase in width of the protected area when the single fan shape was made longer, others by the system detecting objects when travelling forward.

For machines working in open areas this was not a major problem, but for any congested working area the frequency of unwanted alarms was unacceptable. If a warning occurs only occasionally it is easy for the driver to assess whether to take action or ignore it because he knows he is not moving towards the object. But if a warning occurs repeatedly in conditions where no action is required, not only is this very irritating but the driver will cease to consider whether the warning is significant. Even when reversing he will tend to ignore the warning because it registers as an irritation, not as a warning.

Two developments were necessary before the system could provide warnings which were sufficiently selective for the driver to make proper use of them. First, the shape of the protected area had to be adjusted so that it was wide enough close to the machine but not too wide at the maximum distance behind the machine. Secondly, the warnings had to be restricted to only activate when an object was moving closer to the machine.

The radar now creates the protected area by using two beams, one with a wide horizontal spread and one with a much narrower spread. By selecting which beam is used at different distances from the radar the protected area can be tailored to suit the machine. Each radar is pre-programmed with the four most common protection zone patterns, which can be selected via switches on the cab unit, while other patterns can be created and stored in the radar by plugging a laptop PC into the cab unit. Typical patterns are shown in the illustrations accompanying this article.

To develop the radar's ability to reliably identify the direction of movement of objects in the multi-target environment of this application took some time. Nevertheless, this development is now complete and has proved a very important factor in restricting warnings to those the driver wants to hear.

A typical protection zone behind a dumptruck, showing the three stages of warning

The detection zone is divided into three sections with different speed and direction criteria applied to each and different alarm signals in the cab. The closest section is usually set so that any movement will trigger an alarm, so that a person standing close to a stationary machine will initiate a response, but in the outer two sections only movement towards the radar will trigger a response. As a result, if the driver hears an alarm there is either something moving very close to the machine or something further away that is getting closer. In either case the driver can be confident that the alarm justifies checking in the mirrors or TV monitor to see what is causing it.

This development has been so well received by drivers that it has also been applied to the automatic braking systems to provide pre-warning stages. The final braking stage still monitors reverse-gear engagement, as it would be unsafe to apply the brakes when an object is detected, unless the machine is reversing.

Future developments

Currently, the use of both CCTV and hazard-detection systems is much greater in the UK quarrying and mining industry than in other countries, but the rest of the world is catching up. There are now a number of companies working on anti-collision radar and although most of the work is aimed at on-highway applications and intelligent cruise-control systems, work is also being directed at off-highway applications, particularly autonomous dumptrucks.

One alternative approach to the problem of unwanted alarms has been to make detection selective by tagging any people and small vehicles that are at risk. Early trials with radio tagging received a limited response because of the cost and the limited definition of the position of the tagged object with respect to the truck movement. More recent trial systems with ultrasonic tagging give a more detailed definition of the position of the tagged object and may be adopted for some applications where the cost and control of tagging is appropriate.

Other sensors will be developed and the state of the art will undoubtedly move forward but for any hazard warning system to be of use, the driver must be satisfied that the warnings given are meaningful, otherwise this guardian angel will be nothing more than a back-seat driver.

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