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Active safety systems for work zone safety

#ICA4point0

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ABSTRACT

The asphalt industry has been very concerned about the problem of accidents in road works. The fact of using heavy machinery makes these jobs high risk.

A detailed analysis leads to highlight, above all, the following causes with a very serious accident rate:

- Movements of the machinery, rotation or reversing, preventing the driver from detecting workers around and at the rear of the machinery.
- Hiring temporary personnel with little experience in this type of works, which makes them largely unaware of the associated risks.
- Worker's negligence after multiple work hours.

To address these challenges, we propose with this paper, the use of a new Active Safety system that facilitates the asphalting works coordination to avoid accidents between heavy machinery operators and manual activities of workers on the field.

From the worker's point of view, our system behaves like **a new personal protective equipment (PPE)** that automatically warns of dangerous proximity between machinery and workers.

1. INTRODUCTION

Almost all the governments, companies and organizations dedicated to working with asphalt have recognized the need to consider policies to avoid accidents with safety zones and recommend the use of all kinds of electronic devices for safety and traffic control .

In this way, there are multiple proposals on the market for the control of security zones during construction works and roads maintenance.

However, most of the solutions tackle the problem of accidents due to external vehicles intrusion into work areas. Although it is true that this is the source of the most serious accidents in road works, it is also important to note that for asphalt works and due to the type of heavy mobile machines that is used, accidents also occur due to running over foot workers by machinery around.

For this last case, it is for which we have developed a portable **radar** solution, to be installed in mobile vehicles, and a **warning bracelet** for workers.

In this way, workers should wear the bracelet as a new PPE that allows them to be warned before entering areas too close to machinery.

2. ACTIVE SAFETY SOLUTION FOR WORK ZONE SAFETY

Our idea it´s to define safety areas around the vehicles, we can also call them exclusion areas, in order to alert the workers and drivers depending how close the machines are.

After studying different alternatives, we opted for a solution based on active radars.

Thus, our solution is implemented with portable radars, to be installed in the asphalt paving machinery, and active bracelets (PPE) that notify workers when the machine is moving or is in critical proximity, so that accidents can be avoided.

Given the scenario of the asphalt works, the design considerations that we have taken into account for our system have been:

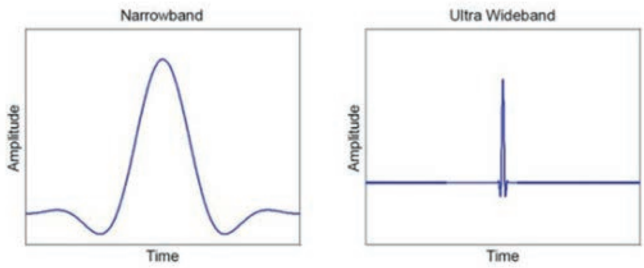
1. Robust, with automatic start and minimum intervention during the works. The system must work 24 hours outdoors and with extreme temperature ranges (winter and summer time).
2. Real-time operation, the detection of workers must be done in less than 1s.
3. Different ranges of distances programming and high precision, up to 100m range and precision better than 1m, so that the solution can be adapted to all types of machines and jobs.
4. Alarms for the vehicle and for the workers on foot. In the case of a worker detection in the areas close to the vehicle, both the driver and the workers must be warned by multiple means (light, sound and/or bracelet vibration).
5. Communications system to store the events (detections) that occur in the cloud and thus be able to monitor the health and safety (H&S) policies from the central management. This information can also become of great value just in case an accident happens.
6. Portable, the radar should be small and can be reused in different vehicles and works. In addition, this would reduce the implementing costs of these solutions for the companies.

To cover all these specs, we have opted for the use of Ultra-Wide-Band (UWB) technologies for our radar solution.

2.1 UWB technology

The term ultra wideband or UWB signal has come to signify a number of synonymous terms such as impulse, carrier-free, baseband, time domain, nonsinusoidal, orthogonal function and large-relative-bandwidth radio/radar signals. Here, the term UWB includes all of these. (The term ultra wideband, which is somewhat of a misnomer, was not applied to these systems until about 1989, apparently by the US Department of Defense.)

Due to the nature of the signals, UWB pulses can be distinguished even in noisy environments, plus the signals are resistant to multipath effects. All of these traits give UWB big advantage over traditional narrowband signals in case of ranging capabilities. Also due to the strict spectral mask, the transmit power lies at the noise floor, which means that UWB does not interfere with other radio communication systems operating in the same frequency bands, since it just increases the overall noise floor, a principle that is very similar to spread spectrum technologies (i.e. CDMA).



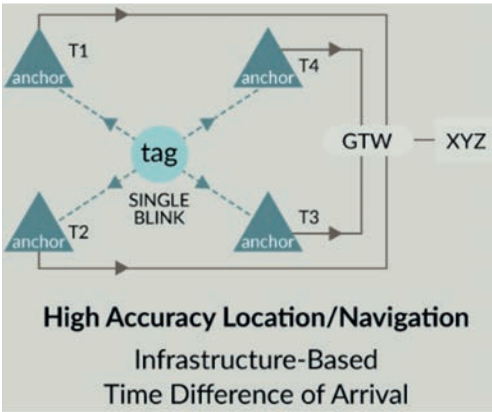
Although it is not the purpose of this document to explain the history of the development of UWB systems, as extensive documentation is available , from our point of view, the maturation of these systems occurred with the appearance of the first SOC from the Decawave company (now part of Qorvo) more than 8 years ago and with the IEEE 802.15.4 standardizations. Until then, the use of this technology was associated with niche products and/or high-budget projects (i.e. Defense). Later on, the market matured and there are now several UWB alternative chip vendors. In addition, specifications for its interoperability have recently been established by the FiRa Consortium, for its use in high-precision positioning applications. This consortium already has more than 100 members, including the most important technology companies. An example of what can be done with this technology is with the Apple iPhone & Airtags Precision Finding feature by the U1 chip.

By using this technology for our solution, we will take advantage of the economy of scale of the UWB industry and thus achieve an economic and high-performance Active Safety solutions at the same time.

2.2 UWB functional modes

Although UWB technology can also be used for communications, we are interested in studying it from the point of view of positioning, so there are basically two operational modes:

1. **Deployments with infrastructure.** In this case the location of the devices (tags) is determined by using Time Difference of Arrival (TDoA) information from the data received by the antennas (denominated anchors from now on) deployed around the scenario.



With TDoA, tags transmit in regular intervals, or refresh rates using brief 'Blink messages". These Blinks are processed by all of the Anchors within communication range. Regardless of their synchronization status, the Anchors will then send all the timestamps to the Real Time Location Server (RTLS). In order to calculate the position of the tag, the RTLS considers only the timestamps coming from at least four anchors with the same clock base. That way, the synchronization is realized wirelessly, with automatically selected Anchors with the optimal coverage being designated 'Primary Anchors' in a regular interval broadcast sync signal.

2. **Deployments without infrastructure.** In this case, the determination of the location is made based on the Two-Way Ranging (TWR) between the terminal and the anchor.

TWR determines the Time of Flight (ToF) of the UWB radio frequency signal, then calculates the distance between the nodes, by multiplying the time by the speed of light. The TWR process is applied between the tag and the demanded anchor, and only one anchor may be actively involved in TWR at a given time slot.

In general, solutions without infrastructure are the most used for work with mobile vehicles and field workers, since they are easy to deploy (just a portable radar in the vehicles) and the detection range is sufficient (better 1m).

For activities that require greater precision in determining the location (i.e. 0.2m or 0.1m), It´s possible to consider deploying antennas (anchors) around the work area. But in this case, it will be necessary to deploy a local positioning server (RTLS & clock sync) in the work area too coordinate all the anchors "blink message" detections, in addition to mounting and dismounting the antennas as the work locations change.

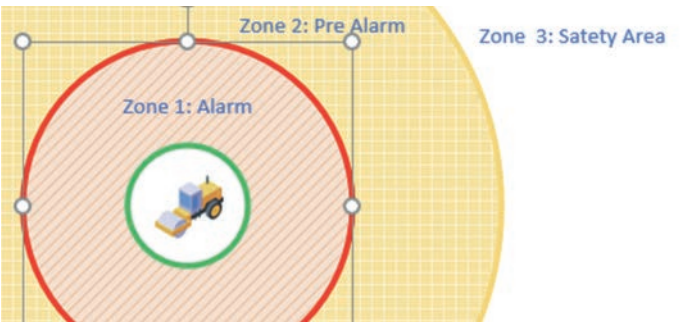
3. APLICAZIONES ACTIVE SAFETY SOLUTION DESCRIPTION

As already explained before, our solution proposes the worker wears a bracelet (also called a tag or tracker) on the body (wrist). Tags for clothing or helmet installation are also available. The tracker has a rechargeable battery several weeks life time (depending on usage). It also has a low battery warning and is recharged with conventional mobile chargers.

Tag detection is performed in circumferences around the base unit. Its radius is defined as a safety distance and can be configured with a precision of centimeters.

In the attached picture we can see:

Workers on Zone 3 are safe. Workers on Zone 2 get an active pre-alarm warning (i.e bracelets vibration and vehicle lights warnings). Workers on Zone 1 get an active alarm warning (i.e. bracelets vibration and vehicles ligt&sound warnings).



Distances should be configured depending on the works and machinery involved.

Each radar can detect up to 40 workers (tags) simultaneously.

The system has two programming distances, one further away for a workers attention zone warning (i.e. < 10 m) and another closer (i.e. < 4 m) for the generation of alarm of dangerous area. In the latter case, the system can even act on the vehicle brakes (just electrics).

Distances are programmed based on the type of vehicle and the type of work performed when the radars are installed on the field.

The system is also configured so that an alarm does not start within a minimum distance (i.e. 1m), so that the driver's movements do not generate false alarms.

By using tags with drivers and field people, it is possible to achieve the double functionality of anti-collision and anti-run over.

Alternatively, if accidents between machines are foreseen, it is possible to install a collision detector in the vehicles for those cases of crossing two machines. This sensor generates a warning to the driver in the event of detection of a radar from another machine. In addition, it is used to generate an alarm on the other vehicle's radar as well.

3.1 Communications

Radars that are installed in vehicles *work autonomously* locally. *This guarantees the operation of the safety system, whether or not there are communications.*

The Active Security system is complemented by a GNSS (GPS) module and a 4G communications module. Both are also installed above the machine cab together with the radar.

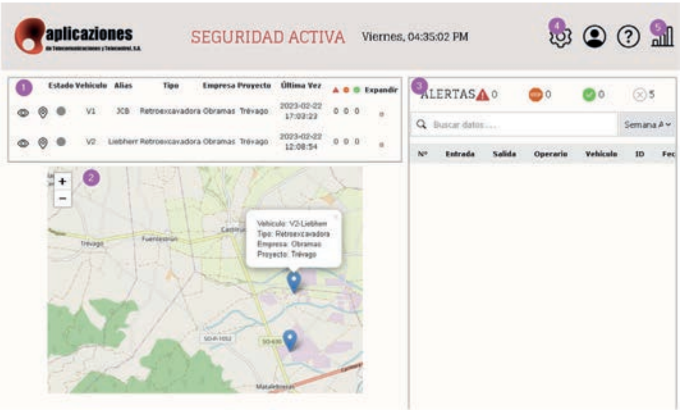
When there are communications coverage in the work area, the radar sends all the messages about the trackers have been detected and the location of the vehicle to the management platform.

In this way it is possible to know from the central system the event data *(Site ID, Vehicle ID, Sensor ID, Detected TAG ID, GPS time GPS position and Vehicle speed) or collision/run over alarm.*

3.2 Platform

A WEB application is available from which system users can access, with their respective access codes, to monitor the machines and the readings of their respective radars. Each user can be configured with the usability restrictions that the system administrator thinks more appropriate.

The platform interface has the following elements

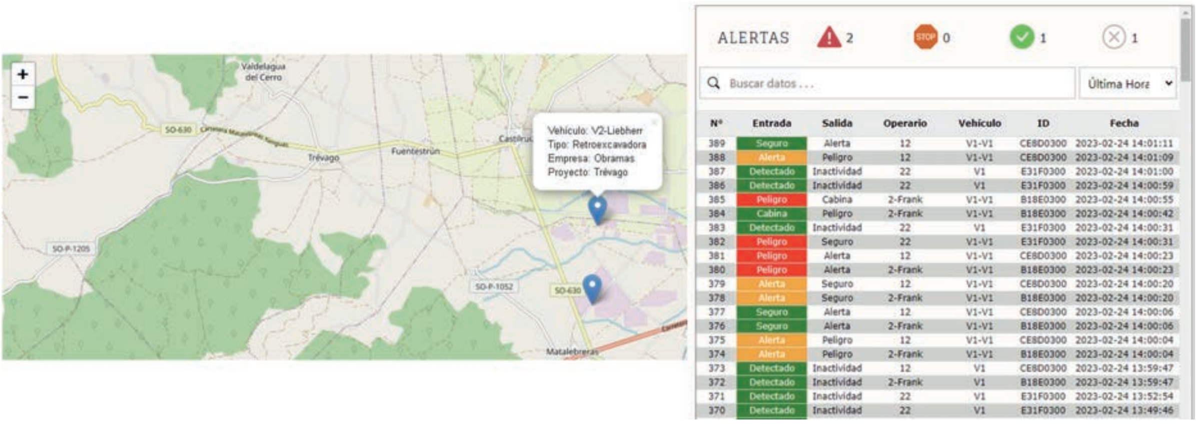


1. **List of vehicles**
2. **Map**
3. **List of generated alerts**
4. **Access to configuration**
5. **Access to statistics and reports**

The Map allows the vehicles connected to the "Active Safety" platform to be viewed in real time, with their corresponding labels to identify each one.

In addition, it is possible to navigate the map using the mouse, the possibilities are the following:

- Movement: You can move around the map by clicking on it and moving your mouse.
- Zoom: To zoom in on the map you can either double click on it or use your wheel on the mouse.



Nº	Entrada	Salida	Operario	Vehiculo	ID	Fecha
389	Seguro	Alerta	12	V1-V1	CE8D0300	2023-02-24 14:01:11
388	Alerta	Peligro	12	V1-V1	CE8D0300	2023-02-24 14:01:09
387	Detectado	Inactividad	22	V1	E31F0300	2023-02-24 14:01:00
386	Detectado	Inactividad	22	V1	E31F0300	2023-02-24 14:00:59
385	Peligro	Cabina	2-Frank	V1-V1	B18E0300	2023-02-24 14:00:55
384	Cabina	Peligro	2-Frank	V1-V1	B18E0300	2023-02-24 14:00:42
383	Detectado	Inactividad	22	V1	E31F0300	2023-02-24 14:00:31
382	Peligro	Seguro	22	V1-V1	E31F0300	2023-02-24 14:00:31
381	Peligro	Alerta	12	V1-V1	CE8D0300	2023-02-24 14:00:23
380	Peligro	Alerta	2-Frank	V1-V1	B18E0300	2023-02-24 14:00:23
379	Alerta	Seguro	12	V1-V1	CE8D0300	2023-02-24 14:00:20
378	Alerta	Seguro	2-Frank	V1-V1	B18E0300	2023-02-24 14:00:20
377	Seguro	Alerta	12	V1-V1	CE8D0300	2023-02-24 14:00:06
376	Seguro	Alerta	2-Frank	V1-V1	B18E0300	2023-02-24 14:00:06
375	Alerta	Peligro	12	V1-V1	CE8D0300	2023-02-24 14:00:04
374	Alerta	Peligro	2-Frank	V1-V1	B18E0300	2023-02-24 14:00:04
373	Detectado	Inactividad	12	V1	CE8D0300	2023-02-24 13:59:47
372	Detectado	Inactividad	2-Frank	V1	B18E0300	2023-02-24 13:59:47
371	Detectado	Inactividad	22	V1	E31F0300	2023-02-24 13:52:54
370	Detectado	Inactividad	22	V1	E31F0300	2023-02-24 13:49:46

Alerts allow you to view in real time all the events that occur on site. This section includes all the information about them, these are the types:

- *Activity:* When a bracelet spends more than a minute without moving or being detected by a sensor, an Inactive alert is generated. Similarly, when an Inactive tag starts moving again, a Detected alert is generated.
- *Zone:* When an active tracker moves between zones, an alert is generated indicating the zone the operator has entered and the zone where he was previously located.

The possible zones status are:

- *Safe:* The operator is at a safe distance from the vehicle
- *Alert:* The operator is at a potentially dangerous distance from the vehicle
- *Danger:* The operator is too close to a vehicle and is in danger

3.3 Active safety subsystems

The key elements of our system are:

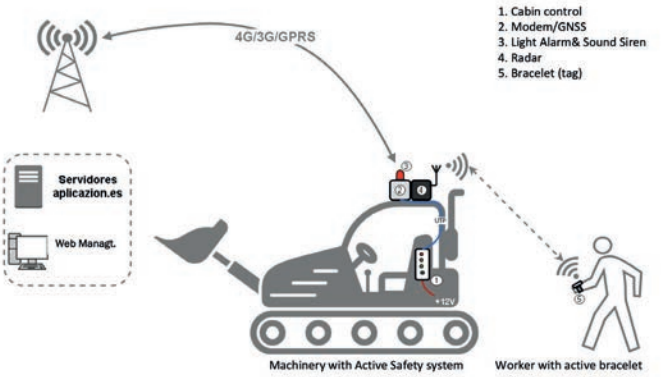
a) A calibrated **radar unit** for precise distance measurement (<0.5m) in real time (response times <0.5sg)

b) **Siren and alert light** outside and inside the vehicle cabin

c) A **bracelet** (tag) for workers, with a vibration alert if they cross a radius of the preconfigured security zone.

d) **GPS tracker with 4G modem** for communication with remote platform. To avoid problems, the radar is autonomous and works without communications, but also if there is network availability, the detection data is sent to a central platform

e) A cloud **Platform** for remotely recording and exploiting data (web management). Thus, it is possible to monitor the H&S compliance and also have legal support just in case an accident happens.



4. CONCLUSIONS

With this paper we have introduced a solution for one automatic Active Safety control around asphalting work zones.

Our solution flexible design allows:

- *Ease of configuration.* The portable radar is installed easily in the different machinery that is used for asphalting the road, the safety distance is defined and that´s all.
- *Minimization of false detections.* Our radar accuracy and technology minimize signal bounces from distances further than those defined in the threshold for alarm generation.
- *Multitude of use cases* (worker crossings, asphalt site safety, machinery in blind zones, machinery in narrow zones, material loading and vehicle collision avoidance)

This solution has been developed based on our own R&D, the equipment is portable (can be moved from machine to machine as needed) and robust (IP66 & IP67) to work in asphalt road works scenarios. Commercialization was launched during the end of 2022.

More info at www.aplicazion.es

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