CONNECTED INDUSTRIAL VEHICLE, AN OPPORTUNITY TO REDUCE RISKS IN FACTORIES

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INTRODUCTION

With the advent of Industry 4.0, the digitization of factories will also affect the industrial vehicles that perform tasks in them. These tasks, dangerous in many cases, range from transporting pallets and tools with forklifts, to maintenance activities with cranes and lifting platforms, to waste collection with different models of backhoes or dumpers. All of these activities are carried out alongside people on foot, non-industrial vehicles or fixed and mobile structures. In addition, they take place in contexts that can be noisy, with poor lighting, blind areas, dust in suspension or mud on the ground. All this, together with the fact that they are generally powerful large tonnage vehicles with articulated arms, makes them probable generators of accidents, which can on occasions be serious, affecting the health of the workers and the working and productive future of the installation.

In the use of commercial vehicles, it is not only the vehicle and the context that are complex, but also the activity itself. Reversing, turning with reduced visibility, driving through narrow aisles or between materials, or moving complex loads are actions in which the driver must pay the utmost attention. This cognitive need causes driver fatigue, stress and even physical injuries to the neck and back throughout the day.

This article presents a study carried out in 9 companies of different sectors and sizes, in which the type of industrial vehicles used in them, the type of tasks performed and the risks arising from their use have been analyzed. Although all the risks detected may be the cause of accidents which, although serious, are not very frequent, in order to have statistically significant data on the relationship between risks and accidents it would be necessary for the companies themselves to record and characterize the incidents over a number of years. The study was accompanied by a survey of drivers to discover their perception. As a result, it is proposed to use an IoT system under the connected vehicle paradigm, which alerts drivers and pedestrians through various types of signals in different risk situations. The proposed IoT system is based on the installation of sensors in vehicles and pedestrians, interfaces with the driver and an SBC computer. In addition, the interconnection of the on-board systems with cameras installed in the plant (communicated by a wireless network), interior geolocation systems, vehicle-vehicle communication or vehicle-pedestrian communication is proposed. All this generates an IoT ecosystem whose main objective is to improve safety, but which could also have a positive impact on the quality and productivity of the factory.

2. RELATED WORK

The operation of industrial vehicles requires a high cognitive capacity. The operator has to process a large amount of information and, in addition, on many occasions does not have all the necessary data due to visibility problems [1]. Owing to their configuration, power or large dimensions, an accident with this type of machinery can cause occupational disabilities and even significant sequelae, if not mortality. For this reason, many researchers have been concerned about the incorporation of technical elements that can help detect risk situations, such as the operator being fatigued [2], pedestrians in the radius of action of a backhoe loader or collisions of mobile cranes with static obstacles [3]. Apart from detection, another important element is how to generate warnings to both drivers and pedestrians of the risk situation while interfering as little as possible with their activity and using as little cognitive capacity as possible [4].

One of the most important fields of work in the improvement of safety has been the design of systems to avoid collisions. Thus, patent [5] presents a system that uses light beams to illuminate an area around the vehicle so that the pedestrian is aware of the area in which he/she could be affected by the machine turning. Other authors, such as [6], have also developed camera-based systems, in this case to detect pedestrians. Other systems have also been proposed, such as those using RFID systems [7] to communicate with pedestrians and detect their presence. Thus, the vehicle detects which pedestrians are within its radius of action and issues a warning signal to the driver.

In the last year, modeling and proposals for omnidirectional obstacle detection have appeared, greatly improving detection speed, and focusing, for example, on the use of depth-sensing cameras [8], or geometric focusing based on road lane markings to estimate obstacle distance from lane boundary crossing [9].

All the works analyzed are mainly focused on acting on the commercial vehicle at an individual level, except for systems to control its position or some other specific functionality. The main contribution of the work presented here is to develop a system that integrates all the functionality required in our approach: an industrial vehicle connected with other vehicles, pedestrians, and with the plant infrastructure, with the ability to detect risk situations and study alternatives to warn the driver.

3. STUDY CONDUCTED

A qualitative study has been carried out in 9 medium and large size companies, representative of different sectors, activities and types of plants, all of which use industrial vehicles. The set of companies has been selected considering the following characteristics: (1) They make regular and continuous use of industrial vehicles. (2) They are from a variety of sectors. (3) They have different operating environments (many machines in the same area, pedestrians, long and short movements, indoor, outdoor, mixed activity, etc.). (4) They have different plant structures (modern, old, well organized, with narrow passages, etc.). The number of machines and types, as well as their functions, also vary considerably. However, virtually all of them are used for pallet transfers with forklifts. Other vehicles used are lifting platforms, pallet trucks, container carriers, backhoes, dumpers, floor cleaning machines, hydraulic hammers, coil lifts, slag bucket transporters, roll trailers, articulated dumpers, and loaders.

3.1. RISKS DETECTED

The analysis carried out on the companies, the vehicles and their activity has made it possible to detect a series of risks that may be potential causes of accidents and whose treatment should lead to an improvement in safety. These risks are described below:

(R1) 90-degree turns with no visibility

(R2) Reversing in traffic areas

(R3) Traffic with limited visibility in areas with pedestrian traffic

(R4) Driving with limited visibility in areas with other machines in motion

(R5) Several machines simultaneously loading goods onto trucks/containers

(R6) Several machines working in one hot spot at the same time

(R7) Workers on foot performing activities within the machine's radius of action.

(R8) Narrowing of traffic lanes and single-vehicle crossings.

(R9) Intersections and exits

3.2. DRIVER SURVEY

In order to characterize the potential users of an ADAS, as well as to determine elements of the preferred driving assistance option in the industrial environment, a survey was provided to a sample of 51 commercial vehicle drivers from the participating companies. The selection of personnel participating in the survey was conducted in order to ensure a wide variety of professionals, vehicles and work environments.

Fisher and Pearson's chi-square tests were performed for the statistical analysis of the survey. The purpose of these tests is to determine whether there are significant differences between groups of drivers (by age, gender, etc.) that make a personalized assistance proposal advisable for each group. Thus, the assistance device would be configurable, providing customized indications depending on the typology of the driver.

The statistical analyses show, for the most part, that there are no significant differences between the groups analyzed, so the results for the complete sample of drivers are presented in this section.

1) Regarding their job description, only 5.88% of the workers consider themselves stress-free, with little or no time for distraction, with little variability of itineraries with their vehicles during the workday.

2) The highest levels of distraction of their activity, in 78% of the cases, are caused by the transit of personnel on their route and, to a lesser extent, by unexpected orders and noise or acoustic contamination.

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3) As regards the equipment in their vehicles, 35% of them have some type of assistance, mainly light signals, rearview mirrors, power steering, rear, side and front vision cameras or an acoustic impact warning system.

4) 60% of drivers consider it of interest to have more warning systems to support their driving, preferably some sort of signal.

5) Regarding the preferred method of warnings, the majority preference is focused on joint sound and light signals, followed by a screen where more information can be seen. These types of assistance are valued as interesting in any environmental circumstance and mostly (in 88% of the cases) when there is something relevant to be reported well or slightly in advance, thus allowing them to process the information and make a decision.

In conclusion, drivers consider it interesting to have driving assistance systems that preferably use sound and light warnings, in all circumstances and with sufficient advance warning to be able to react appropriately.

4. ASSISTANCE PROPOSAL

In order to make it possible to reduce the risks detected in the study, several elements of assistance have been defined, which have been linked to the different risks detected. The proposal is as follows:

1. Representation of the location of the vehicles on a floor plan (R1, R4, R5, R6, R8, R9). The real-time location of each vehicle is displayed on a screen.
2. Information box on a HUD or display indicating the number of pedestrians and machines on the perimeter (and the direction in which they are located) (R5, R6, R7).
3. Warning lights of two different colors, indicating the presence of pedestrians and machines in the area (R5, R6, R7). Their purpose is to generate a first alert.
4. Seat belt vibration when there are pedestrians on the perimeter and the machine has started to make a turn (R7).
5. Vibration of a wearable device on the pedestrian's jacket when he/she is on the perimeter of the vehicle and the vehicle starts to turn (R7).
6. Beep when an obstacle (pedestrian or vehicle) is encountered ahead, behind, a tight turn, narrowing or exit (R1, partially R2, R3, R4, R8, R9).
7. Beep when the vehicle is approaching a junction and another vehicle is also approaching in a perpendicular direction (partially R1, partially R2, R4, R9).
8. Incorporation of a traffic light in front of a junction, narrowing, exit or tight turn that illuminates an amber or red light (R1, partially R2, R3, R4, R8, R9). Using connected vehicle techniques, the color of the traffic light could also be projected on a HUD in the vehicle.
9. Laser lights illuminating the perimeter when a pedestrian enters the vehicle's action zone (partially R3, partially R5, R7, partially R9).

These proposals were presented to the participating companies and were well received. Some companies expressed their intention to become involved in a new project to implement a working prototype of the proposal.

5. LOW-COST IMPLEMENTATION

For the system to be effective in diverse working environments, it must have a highly configurable design. By installing different sensors and interaction elements and using a configuration file to define the types of actions required, the system's actions can be adapted to all the work environments studied with minimal modification. The equipment installed in the vehicle can be combined with other equipment deployed in the factory itself or in the employees' work clothes.

To determine the feasibility of the system, two prototype control systems have been developed (one with a graphical interface and one without) using a Raspberry PI SCB computer. The objective will be to demonstrate that a system of these characteristics (configurable and with a certain degree of intelligence) can be implemented in a low-cost device. The general scheme of the developed software is shown in Figure 1.

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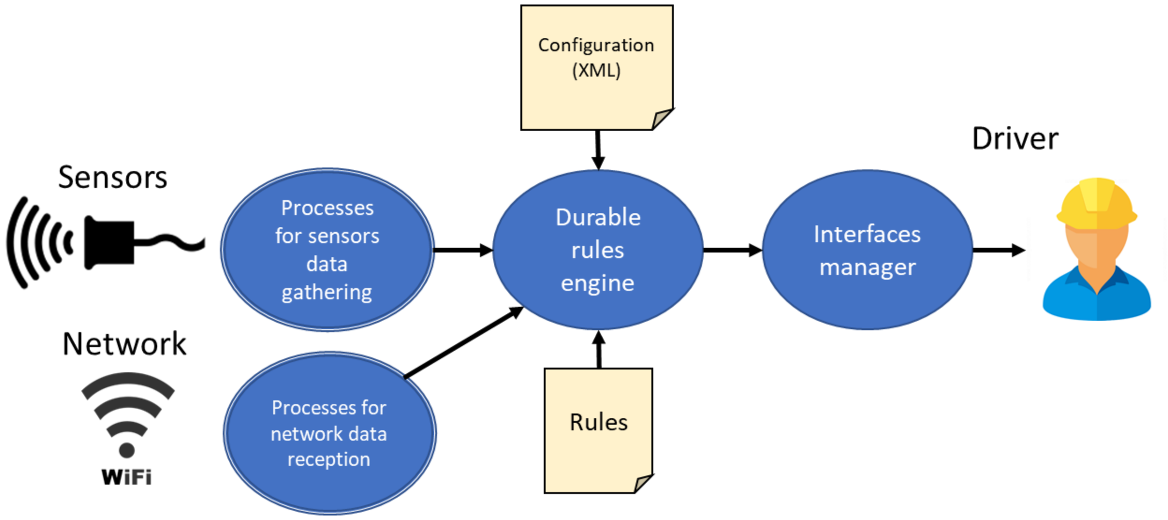

Figure 1 General scheme of the developed software

The system has a multithreaded structure where there is a thread to manage data collection from each of the sensors directly connected to the device and another to collect, via the communications network, information from all the detection equipment installed in the factory (e.g. cameras). These threads, when they detect an event, trigger the execution of the rules engine to make the appropriate decision. This execution will be performed within a critical section. When necessary, the rule network will send a message to the interface manager to activate different types of means of communication with the vehicle driver (visual and audible). For the visual warnings, 3 types of elements have been used: interface to display on screen/HUD/miniprojector, indicative LEDs on the steering wheel and LED strips on the sides of the front glass. For the display interface, two designs have been created: a textual interface based on characters and another with a more complex graphic interface. In Figure 2 a screenshot of both interfaces can be seen showing the representation of the 4 zones (front, rear, left and right side) where pedestrians may be at risk (3 colors are used depending on the distance: green/no risk, orange/moderate risk, red/high risk). Red warnings are associated with an acoustic warning signal. On the graphic interface there is an activated alarm coming from a fixed camera. In addition, the LED systems for the dashboard and sidebars are displayed.

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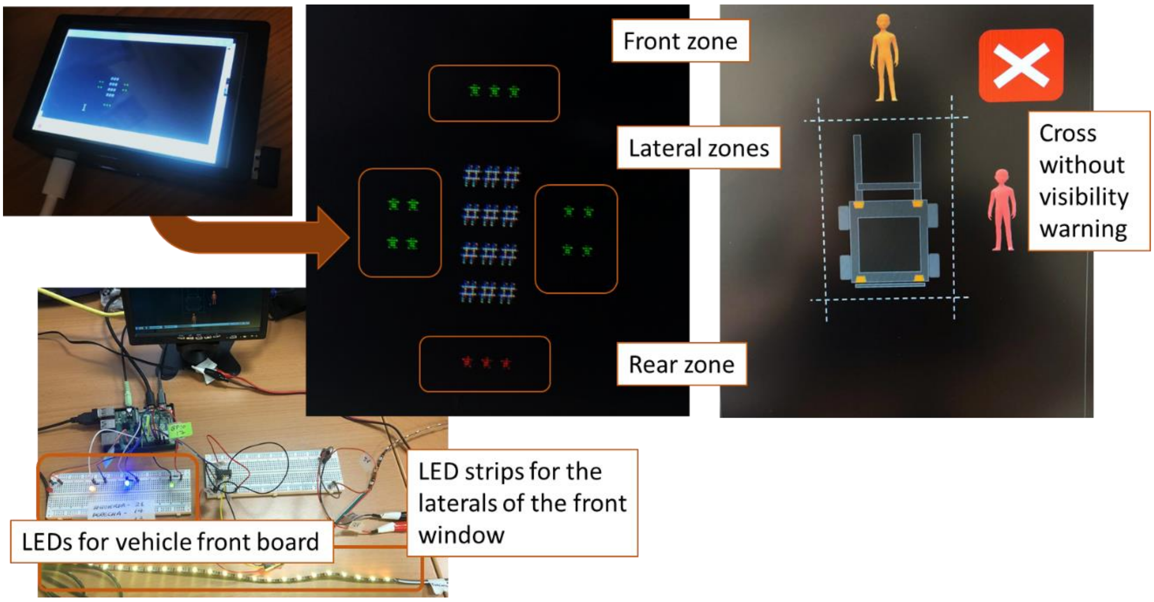

Figure 2 Prototype executions with textual and graphic interface

To carry out the performance analysis, events were generated from 4 simulated sensors connected to the equipment itself and from a network camera that transmits events through a WI-FI communications network. Three scenarios were evaluated by varying the event generation intervals (Table 1). To determine whether the system can withstand the load, CPU and memory utilization levels were analyzed. The results of this simple evaluation conclude that resource consumption is minimal, and the system does not present implementation problems with either the textual or graphical interface.

Also, the system designed really seeks to optimize energy consumption since it will be connected to the vehicle's battery. As the system will carry a screen, the computer, LED strips, belt vibrators, etc., the consumption of the components should be as low as possible. The current prototype is still undergoing laboratory tests to evaluate its functionality and usability. In a second phase, it will be implemented in industrial vehicles to observe the typical problems that occur in intensive use in difficult contexts (dust, constant starting and stopping, etc.).

Scenario	Result in the prototype	Textual interface	Graphical interface
Sensors and camera sending events every second	Maximum total CPU utilization:	10,2%	10,5%
	Maximum memory usage:	< 5%	< 10%
Sensors and camera sending events every 1 and every 2 seconds	Maximum total CPU utilization:	8,5%	9,3%
	Maximum memory usage:	< 5%	< 5%
Sensors and camera sending events within 5 to 7 seconds	Maximum total CPU utilization:		6,8%
	Maximum memory usage:	< 5%	< 5%

Table 1: Results of the performance analysis

6. DISCUSSION AND CONCLUSIONS

In this work, the needs for driving assistance in industrial vehicles operating in very diverse work environments have been evaluated. Several case studies in companies of different productive sectors have been analyzed to characterize the risk situations in which driving assistance is needed. The study is complemented with driver surveys to determine the best method of assistance for dealing with risk situations that may arise.

Having analyzed the situations, the risks involved and the possible actions, it can be concluded that they all fall within two different work environments: firstly, a situation where machines are constantly circulating with loads. This occurs in factories and processing centers where goods are moved on pallets between production lines, to warehouses or truck loading. In this situation, small machines moving at medium/high speed are used. It is a very dynamic scenario characterized by the coexistence of machines that are in constant circulation. The second situation is where several vehicles and workers are working around a hot spot. This scenario is much more static as the machine movement is around the point and there is less movement. Typically, larger vehicles such as backhoes or loaders are used.

It is also important to highlight that drivers consider that driving assistance systems should preferably use sound and light signals, in all conditions and with sufficient advance warning to be able to react appropriately. This opinion of experts on driving in industrial environments is key in the design of assistance systems and has been taken into account when implementing the system proposed in this article.

Another relevant issue when implementing this type of system must be its reduced cost and reliability, so that the driving support system does not deter businesses from installing it, currently not mandatory. Thus, the technological proposal made in this work has considered all the aspects analyzed and the core of the system (collection, intelligent system and interface) has been implemented in a Raspberry PI type SBC. The evaluation carried out indicates that the use of this type of SBC is perfectly feasible. In addition, as the use of resources is very low, there is capacity to incorporate more complex interfaces or activity recording systems (logs) without the performance of the equipment being a problem.

Future work is mainly focused on the construction of a fully operational ADAS. However, within this process there are certain aspects that will require lengthy research. These include work on usability or interaction with the driver. The analysis of the perception processes, means of interaction, response times, cognitive requirements generated by the signals, discomfort or distractions produced, system resistance test and the cost-benefit generated will all be very important for the system to satisfy its direct user.

REFERENCES

[1] A. A. Yusof, et al. , "Modern practical application and research on teleoperated excavators control, feedback and perception issues in post disaster recovery operation," 2015 IEEE International Symposium on Robotics and Intelligent Sensors (IRIS), Langkawi, 2015, pp. 179-185, https://doi.org/10.1109/IRIS.2015.7451608.

[2] J. Li et al., "Evaluating the impact of mental fatigue on construction equipment operators' ability to detect hazards using wearable eye-tracking technology," Automation in Construction, 105, 2019, 102835. https://doi.org/10.1016/j.autcon.2019.102835

[3] S. Han et al., "3D visualization-based motion planning of mobile crane operations in heavy industrial projects," Journal of Computing in Civil Engineering, 30(1), 2016. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000467

[4] T. A. Sitompul and M. Wallmyr, "Using augmented reality to improve productivity and safety for heavy machinery operators: State of the art," In The 17th International Conference on Virtual-Reality Continuum and Its Applications in Industry, pp. 1-9, Nov. 2019. https://doi.org/10.1145/3359997.3365689

[5] LINDE MATERIAL HANDLING GMBH. Driver assist device and industrial truck with driver assist device. 2012

[6] A. Lang and W. A. Günthner, "Evaluation of the Usage of Support Vector Machines for People Detection for a Collision Warning System on a Forklift," In Proceedings of the International Conference on HCI in Business, Government, and Organizations (pp. 322-337). Cham: Springer. 2017 http://dx.doi.org/10.1007/978-3-319-58481-2_25

[7] J. Byung-Wan et al., "Proximity Warning and Excavator Control System for Prevention of Collision Accidents," Sustainability 2017, 9, 1488. https://doi.org/10.3390/su9081488

[8] X. Zhao et al., "Omni-Directional Obstacle Detection for Vehicles Based on Depth Camera," IEEE Access, vol. 8, pp. 93733-93748, 2020, doi: 10.1109/ACCESS.2020.2993934

[9] A. Ali et al., "Real-time vehicle distance estimation using single view geometry," In The IEEE Winter Conference on Applications of Computer Vision, pp. 1111-1120, 2020.

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SUPPLEMENTARY MATERIAL

Sector	Size	Type of vehicles	Vehicle activities
Dairy	large	Forklift truck, platform lift, pallet truck, container truck, container carrier	Goods movement and vehicle loading
Manufacture of capital goods	large	Forklift truck, platform lift	Movement of parts, access of workers to areas at heights, etc.
Iron and steel auxiliary	medium	Backhoe, dumper	Earthwork
Manufacture of cardboard packaging	medium	Forklift truck	Transportation of materials and loading of vehicles
Machinery rental	large	Forklift truck, platform lift	All types of work in all types of contexts
Chemicals	large	Forklift truck	Movement of vats with chemical products
Pneumatic and hydraulic equipment manufacturing	large	Forklift, pallet truck, pavement cleaning	Movement of materials, cleaning of the factory
Iron and steel auxiliary	medium	Forklift truck, hydraulic breaker, coil elevator, slag bucket transporter, roll trailer, articulated dumper, loader, loader, etc.	Transportation and treatment of waste, transportation of large materials
Manufacture of walkways and escalators	large	Forklift truck	Escalator transport

Table 1: Summary of the 9 companies in the study and their vehicles

Detected risk	Description
(R1) 90-degree turns with no visibility	There are areas where machines must make 90-degree turns where there is little or no visibility due to the fact that materials are stored or machinery is installed on the sides of the traffic area. The possibility that pedestrians are on the road in the blind spot, that a machine is encroaching on the road to load material, or simply the difficulty of adjusting to the delimited spaces, can make the maneuver dangerous.
(R2) Reversing in traffic areas	There are occasions when carrying a load prevents the operator from having a clear view of the roadway. In these situations, good practice indicates that the operator should drive in reverse to be able to see the track clearly. However, during this maneuver, the load is lost from sight, making it more complicated to operate the machine and causing an obviously higher risk situation.
(R3) Traffic with limited visibility in areas with pedestrian traffic	In most factories, machines coexist with the movement of people on foot. In some cases, pedestrians have to cross the lanes marked out for vehicles or they may simply encroach on them accidentally or unintentionally. If these encroachments take place unexpectedly or in areas with reduced visibility, they can lead to accidents with very serious consequences.
(R4) Traffic with limited visibility in areas with other machinery in movement	In many installations there is a lot of movement of materials, there are works and maintenance of great importance, and it is common on these occasions that several machines are operating simultaneously in the area. Any carelessness can lead to a collision. This situation is aggravated when visibility is poor and/or noise is high.
(R5) Several machines simultaneously loading	The loading and unloading of trucks, containers or wagons is an important activity in many industries and it is common for several machines to work simultaneously in order to minimize the time spent. In this context, there will be constant forward and backward

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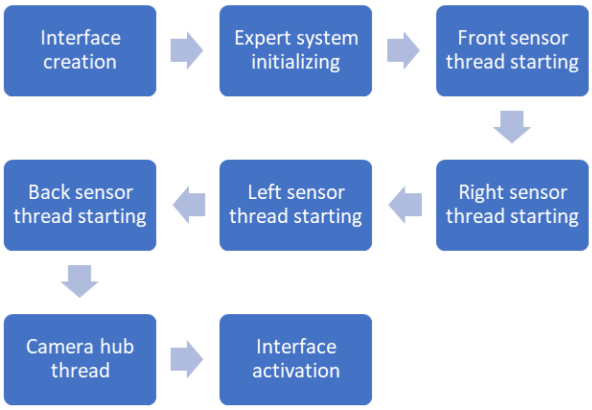
goods onto trucks/containers	movements, simultaneous to the movements of the machinery, giving rise to potential collision points.
(R6) Several machines working in one hot spot at the same time	In certain types of work, it is necessary for several machines to work around a hot spot performing different types of activities. The work of the machines may cause drivers to be unaware of the location of one of the other vehicles at a given moment and an incident may occur.
(R7) Workers on foot performing activities within the machine's radius of action.	It is common to carry out this type of tasks, causing significant risk situations between vehicles and workers on foot.
(R8) Narrowing of traffic lanes and single-vehicle crossings.	There are situations within a factory in which the machine traffic lanes are narrow or overlap. In such cases, either the lanes are narrowed as much as possible or a passing lane is created in one of the directions. Such areas are prone to generate more accidents if one of the drivers is absent-minded or driving faster than the recommended speed.
(R9) Intersections and exits	It is very common for facilities to have exit gates to communicate their warehouses with outside areas. It is not so usual, but sometimes occurs, that companies have several of their work areas on opposite sides of a road, on other occasions the lanes where vehicles operate cross each other. In all these situations the probability of an accident increases ostensibly.

Table 2: Risks detected in the analysis of the companies, potential causes of accidents

Type	**Feature**
Model	Raspberry PI 4 Model B rev. 1.1
Memory	4 GB
SO	Linux 4.19.97-v7l+

Table 3: Characteristics of the Raspberry Pi used in the support prototype



a) Main thread outline

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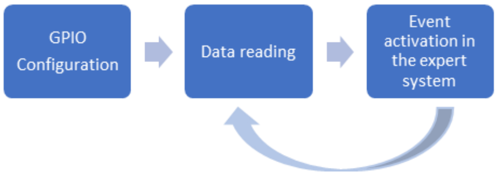
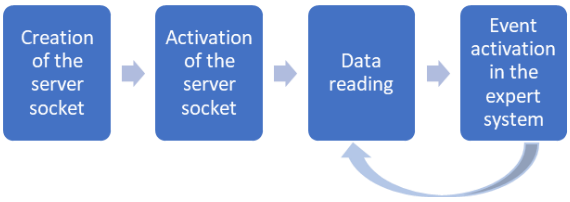


b) Sensor wire diagram



c) Schematic diagram of the camera receiving thread

Figure 1 Schematic diagrams of the software structure of the support system

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