CONFERENCE PAPER 3

2nd International Conference on Asphalt 4.0

Artificial intelligence applied to safety mobile equipment SAFETYPAV project

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ABSTRACT

Construction sector, along with agriculture and industry, is one of the sectors that historically leads the incidence rate of occupational accidents in Spain.

Within the field of paving asphalt mixes, attempts to improve safety through devices integrated into the machinery, capable of generating alerts and even stopping it, have not been very fruitful to date. Most of these devices are based on proximity sensors of different kinds that have not been effective in an environment where the casuistry is tremendously variable, with reduced spaces and the presence of obstacles and construction personnel. These systems produce an excess of warnings that saturate the machinery driver or operators, constantly stopping the machinery and interrupting production.

Addressing this problem from a new approach, Pavasal company, in collaboration with the Tekniker, are developing a research project with funding from the Ministry of Science and Innovation (Red.es) in which, through a advance environment perception system using Artificial Intelligence (AI), based on the information provided by a set of RGB-D cameras located around the machinery, aims to discriminate when there is a real danger of an accident and when, despite the fact that there is a high proximity between the personnel and machinery, the situation is not imminently dangerous..

This advance environment perception system must be able to discriminate and identify the presence of a human or other obstacles and its relative movement with respect to the machinery (speed and direction) and evaluate if it is in a possible interception trajectory. The system will generate an alert or act only in those cases in which the distance necessary for braking and stopping the machinery could make an accident possible, thus avoiding unnecessary interruptions or overloading of warnings..

Keywords: Safety at work, Deep learning, Artificial Intelligence.

1. INTRODUCTION

Until recently, global digitization in the construction seemed like a pipe dream due to the high variability in the constituent stages that occurred outside of a conventional industrial environment. The vast amount of data required made a fully controlled process unfeasible, until the advent of Artificial Intelligence (AI).

Currently, three factors are contributing to slow down the adoption of AI in the construction industry:

- Existing legislation that still does not provide sufficient guarantees to introduce an AI into construction processes.
- Scarcity of knowledge and technological talent in organizations.
- A corporate culture resistant to adopting new construction methods.

However, the automation of construction processes appears to be inevitable in a social context the efficiency of natural resources and the safety and well-being of workers takes precedence.

In this regard, other industrial sectors with a more manufacturing-oriented tradition have already achieved significant levels of development in AI, providing the construction with a blueprint to follow.

However, the technological challenge is immense due to the diverse nature of an incredibly variable environment, both in terms of its location and the variability of parameters to be controlled within each of the locations. In the case of a mobile machine such as the scope of this project, it must address at least the following challenges:

- Identifying the environment.
- Detecting the presence of obstacles (humans and objects).
- Understanding changing environments.
- Operating under adverse conditions (construction site and its surroundings).

The proposed solution to these challenges is based on AI algorithms capable of real-time responses and solving logical problems for decision-making in the following areas:

- Perception.
- Localization
- Planning.
- Performance.
- Control.

Undertaking a project to automate a construction process demands careful consideration of the best approach, as there are distinctions between robotizing an existing machine and opting for a commercial robot and adapting it to a specific need. From a technological perspective, robotics already offers many alternatives for automating construction, making it crucial to define the requirements accurately in order to select the most suitable option available. Depending on the problem to be solved, the level of technological integration and the approach to the solution will differ. Certain functionalities of construction machines, for safety or efficiency reasons, may be better kept outside the operator's decision-making space. These automations don't necessarily replace the operator but provide assistance in case of certain operations are suboptimal or if a dangerous situation arises. The lifespan of construction machinery is long and, sometimes, the current needs are not fulfilled by machines developed decades ago. This has given rise to a technological trend called "retrofitting", which involves modifying existing machinery by incorporating new hardware and software to grant them autonomy.

This project combines all these concepts and aims to address the need for the implementation of an autonomous decision-making system in safety issues, both in existing machinery and newly manufactured machinery, while minimizing the intervention of the operator of the mobile equipment.

This need is supported by accident statistics related to mobile machinery, in general, and their use in construction, in particular. Fatal accidents involving mobile machinery in the country increased by 21.2% between 2015 and 2019, with operators and drivers of mobile machinery experiencing more workplace accidents than five years ago. Specifically, work accidents with these individuals have increased by 39.5%, rising from 33,993 accidents in 2015 to 47,445 in 2019.

Regarding fatalities, the numbers are equally concerning. In the last five years, fatal work accidents increased by 21.2%, with 113 deaths in 2015 rising to 137 in 2019. The majority of accident victims are men and, when it comes to types of injuries, dislocations, sprains, and strains represent half of the cases, with limbs being the most affected body parts, accounting for 60% of the cases. The construction sector, along with agriculture and industry, historically leads the incidence rate of occupational accidents in Spain.

	LEVES		GRAVES Y MUY GRAVES		MORTALES	
	Nº ACCIDENTES	%	Nº ACCIDENTES	%	Nº ACCIDENTES	%
Movimiento del cuerpo como consecuencia de o con esfuerzo físico (por lo general provoca una lesión interna)	17.758	29,7%	28	4,2%	0	0,0%
Movimiento del cuerpo sin esfuerzo físico (en general provoca una lesión externa)	11.331	19,0%	69	10,3%	0	0,0%
Pérdida (total o parcial) de control de máquinas, medios de transporte - equipo de carga, herramienta manual, objeto, animal	10.728	18,0%	104	15,5%	21	26,3%
Resbalón o tropezón con caída - Caída de personas -	10.108	16,9%	289	43,2%	28	35,0%
Rotura, fractura, estallido, resbalón, caída, derrumbamiento de Agente material	5.273	8,8%	110	16,4%	9	11,3%
Desviación por desbordamiento, vuelco, escape, derrame, vaporización, emanación	1.838	3,1%	9	1,3%	0	0,0%
Otra Desviación	946	1,6%	19	2,8%	22	27,5%
Ninguna información	934	1,6%	11	1,6%	0	0,0%
Desviación por problema eléctrico, explosión, fuego	499	0,8%	22	3,3%	0	0,0%
Sorpresa, miedo, violencia, agresión, amenaza, presencia	319	0,5%	8	1,2%	0	0,0%

Figure 1: Accident rate data by type in construction in Spain (2017).

With this data, there is an urgent need to improve safety in the workplace, not only for the operators who use or are near the work carried out by mobile machinery, but also for the bystanders. In cases where construction takes place in urban or interurban environments, users may be at risk due to their proximity to the operating mobile machinery.

An example of safety development in mobile machinery is the implementation of collision avoidance systems. There are solutions available in the market that warn the operator about the risk of collision or even have autonomous capabilities to stop the machine when detecting potential danger.

However, although mobile machinery is equipped with detection elements that allow the identification of objects, these systems are heavily influenced by the environment and the ongoing activities that require personnel to be close to the machine. As a result, they may not be able to identify potential hazards adequately. These systems are typically based on:

- RADAR: Capable of identifying the proximity of an object to the mobile machinery and its relative distance. However, it cannot distinguish between objects and people, and its constant proximity warnings for different objects hinder the concentration of the machinery operators. Additionally, weather conditions or changes in the machinery's working angle can distort the radar waves, making the system less effective.

Figure 2: RADAR System tested.

- Camera-based image monitoring system: This method allows for the identification of individuals in environments where mobile machinery is operating. However, it is highly inefficient due to the level of attention required from the machinery operators to constantly monitor these images while performing their tasks.

Figure 3: Image system in mobile machinery, diverting the operator's attention.

Additionally, it should be noted that, although the work environment is dangerous and constant concentration is required, there are situations where machinery can approach operators/users at close range without endangering them, for instance, when a person is behind a wall at a distant distance without the risk of being hit by the machinery since it is moving in a different direction. Therefore, the project **"ARTIFICIAL INTELLIGENCE APPLIED TO SAFETY MOBILE EQUIPMENT (SAFETYPAV)"** aims to develop an accident prevention system on construction sites by applying Artificial Intelligence to real-time images captured through sensors incorporated into machines.

The specific objectives of the project are as follows:

- Reduce accidents associated with activities carried out on the construction site that endanger the safety of both present workers and users who may be exposed to heavy machinery operations.

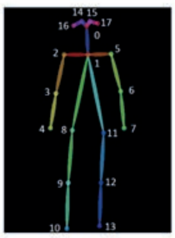
- Implement an autonomous solution that enables decision-making regarding safety, resulting in a system that allows control over the machinery and reduces the risk of incidents due to the reduction of accidents in situations beyond human operators' control.

To achieve this, it is desired to implement a system capable of not only detecting people but risky situations, too. The first step is the accurate identification of operators in hazardous situations. For this purpose, TEKNIKER has a technology capable of measuring the minimum distance between a machine and a person, as part of the safety strategy for speed and separation between machinery and individuals in collaborative robotics scenarios.

The technology is called Proximity Detection System (PDS) and is patented under ES2681123. It can measure the relative distance between a machine and an object in its proximity by using point cloud information provided by a sensor. In subsequent developments, the system has evolved to distinguish between objects and different parts of a person's body, thanks to the integration of AI algorithms. The system can detect key points on a person's body based on RGB image and calculate the relative distance between an object and those body parts based on point cloud data from an RGB-D sensor.

The Visual Object Detector component based on a Deep Learning (DL) model is responsible for individually monitoring each key point of a person's body parts.

0	Nose
1	Neck
2	Left shoulder
3	Left elbow
4	Left wrist
5	Right shoulder
6	Right elbow
7	Right wrist
8	Left hip



6	Right elbow
7	Right wrist
8	Left hip
12	Right knee
13	Right ankle
14	Left eye
15	Right eye
16	Left ear
17	Right ear

Figure 4: Body part detection keypoints.

As can be seen in Figure 4, the keypoints are detected on the RGB image and the alignment between the RGB image and the pointcloud allows positioning those points in the depth image. Thanks to the depth information of the RGB-D camera, the distance between the camera and each of the keypoints can be obtained (Figure 5).

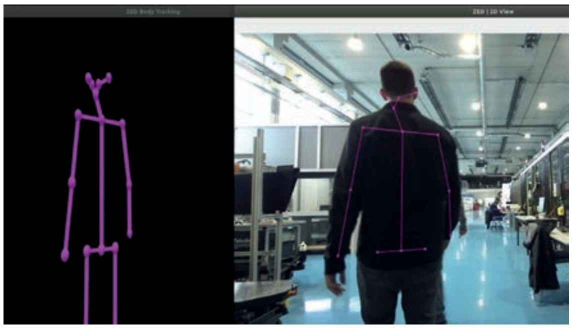


Figure 5: Real-time calculation of keypoints for a person.

This technology will serve as the foundation for the project's development, incorporating risk/no-risk decision-making evaluated by the AI system. Therefore, the main objective of the project is to achieve an autonomous solution that can be employed in all construction sites where the company operates. This will be accomplished by integrating advanced AI-driven data and real-time image visualization into a technological tool that prioritizes safety on the construction site. The solution will take into account the following aspects:

- Identification of risk situations: Assessing the risk based on the environment in which the mobile machinery operates.
- Identification of relative position and kinematics of machinery and operator/user.
- Implementation of measures on the mobile machinery to prevent accidents, which are typically severe for the operator/user involved in such collisions.

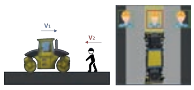
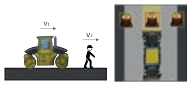
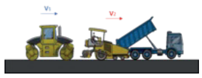
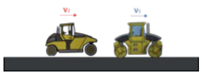
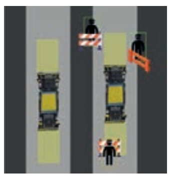
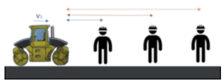
2. START WORKS

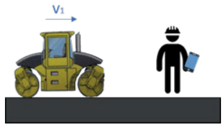
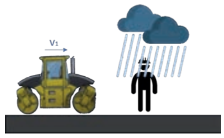
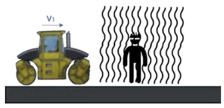
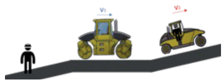
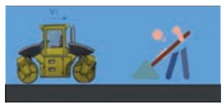
As the start of the actions to obtain the prevention system, some tests were carried out at the PAVASAL facilities to test and analyze the validity and limitations of the human detection system developed by TEKNIKER, which had never been used in the context of asphalting process.

The system is based on the use of a set of RGB-D cameras and the real-time analysis of the images obtained applying deep-learning models. It is a system that is not certified from a security point of view, but it can be used as an assistant for the driver of the vehicle, who can be alerted in the event of a situation that requires his attention.

2.1 Definitions of experiments performed

Prior to TEKNIKER's visit to the PAVASAL facilities, the following hazardous situations were defined in order to generate a custom dataset and perform evaluation:

TEST	Ddescription	Image
1	Worker moving forward (v2) facing the machine (v1) located in its trajectory --> Serious danger. Outside its trajectory --> No danger.	
2	Worker moving backward (v2) without seeing the machine (v1) located in its trajectory --> Serious danger. Outside its trajectory --> Low danger.	
3	Detection of people in different postures (squatting, kneeling, lying down).	
4	Roller compactor (v1) manoeuvres close to the paver (v2).	
5	Roller compactor (v1) manoeuvres close to the tyre compactor (v2).	
6	Detection of objects in the path of the tandem: shovels, sacks, cones, cars.	
7	Detection of workers with tools: shovels, wheelbarrows, etc.	
8	Detection of people behind fences or barriers.	
9	Non-detection of any objects or people.	
10	Calculation of trajectories for the different turning angles of both the rear and front rollers of the tandem. Identification of potential hazards if any person or object is in the described trajectory.	
11	Detection of people at different distances (less than 3.5m, between 3.5 and 8m, more than 8m).	

TEST	Ddescription	Image
12	Detection of people between machinery.	
13	Detection of people with mobile phones or electronic devices.	
14	Detection of people in rainy conditions.	
15	Detection of people through vapours.	
16	Detection of people on terrain with varying inclinations.	
17	Detection of people when the color of their clothing blends with the surroundings.	
18	Without elements to verify false positives.	

The locations of the RGB-D cameras used in the tests were also defined, although different configurations were tested to ensure the absence of blind spots that could hinder the proper detection of the elements to be identified. (Figure 6).

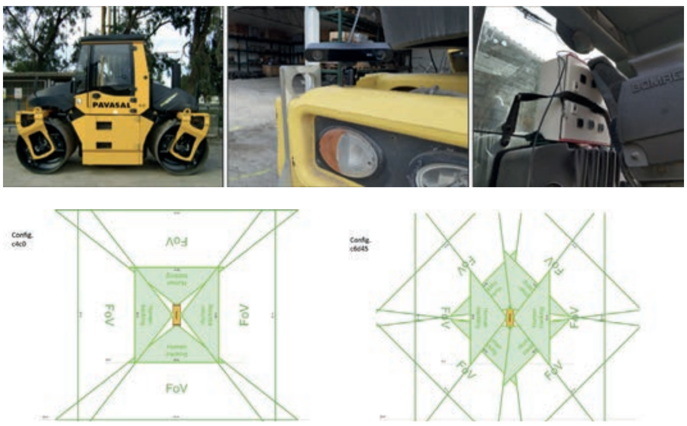


Figure 6: Placement of the cameras on a mobile machine and several camera locations tested.

2.2 Hardware

To carry out the experimental part, several hardware elements were studied and designed, and the following configuration was ultimately chosen (Figure 7):

- Mini PC: NVDIA Jetson Nano (Maxwell GPU, ARM Cortex A57, 16GB eMMC).
- Depth Cameras: ZED 2i, polarized and 2.1mm lens.
- Power: Battery connection.
- WIFI network for remote connection.

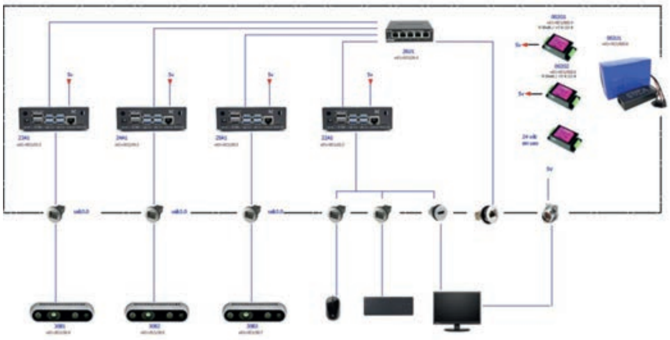


Figure 7: Diagram with the different hardware elements.

This system with the developed algorithms will be capable of detecting both dynamic elements (workers/pedestrians) and static elements using point cloud technology, resulting in an integrated solution. It will not only detect risky situations, but also common elements that may come into collision with the mobile machinery.

2.3 Results evaluation process

Each camera detected the presence of humans by detecting body parts using a deep learning model in real time. All the frames captured by each camera and by each test were stored with the following structure for later analysis:

- Frames with the presence of humans
- Frames without the presence of humans

Raw recorded videos and videos processed by the human detection model were also stored. To verify the results obtained, a visual validation of each of the frames categorized by the model was carried out, checking whether the classification had been carried out correctly or not. An image with humans was considered to be correctly categorized if the humans closest to it were correctly detected. Otherwise, it was considered incorrectly categorized..

On the other hand, for the images categorized without the presence of humans were considered correct if there is no presence of a human or any part of their body. The metric used was:

$$\text{Test accuracy} = \frac{\text{Images correctly detected}}{\text{Total images}}$$

3. RESULTS OF THE TESTS

Over several days, various planned tests were carried out with the cameras installed, either on a roller compactor or on a specifically designed device for image recording and execution. These tests simulated the camera's height placement, and different configurations were tested to ensure there were no blind spots.

The tests were conducted under various lighting conditions throughout the day, and the results obtained were entirely satisfactory. It was confirmed that the system successfully acquired images and identified, in the scenarios set up, all the situations that can occur at a construction site. Additionally, the acquisition of the point cloud, which allows the identification of static elements, was also verified.

Figure 8: People detection and point cloud.

Furthermore, the system was tested to verify the potential trajectories of users in relation to its position, allowing for the early identification of potential collision situations to be avoided. As shown in figure 9, the right side of the image illustrates the trajectory and speed of users within the system's field of view.

Figure 9: Person detection standing/running and trajectory relative to the machinery.

All of this progress serves to keep advancing in the project with the ultimate goal of achieving a higher-level architecture to predict the identified risk situations based on the intentions of the worker or pedestrian. This will enable the system to take preventive actions and avoid potential accidents effectively. To summarize, the project's status after the conducted tests can be represented in figure 10, where adequate detection and trajectories have been achieved for the identified situations during the project.

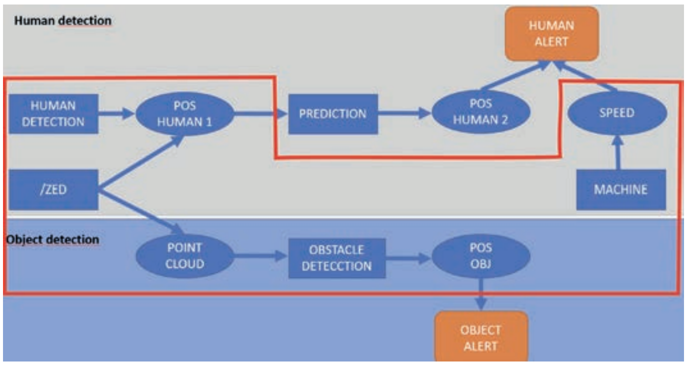


Figure 10: Software architecture of the project. In red, tasks developed.

4. CONCLUSIONS

The most important conclusion from the conducted tests is that the current system, based solely on detecting people and estimating their distance from the vehicle at a specific moment, serves as a starting point for determining the positional state of operators in relation to the operating machine.

Currently, the SAFETYPAV system is also capable of detecting safety elements present at the construction site, such as fences, barriers, New Jersey barriers, etc. and estimating whether the person is behind or in front of them based on the pointcloud.

The next steps to be developed in the project will be determining the movement and relative speed between the person and the mobile machinery. At low vehicle speeds or when the person is moving away from the vehicle, the instantaneous distance alone is not indicative of risk. Calculation of the relative speed between the vehicle and the human will require using previous image sequences and the frame rate, using the person's activity as a criterion (performing specific tasks, running, using a mobile phone, , looking at the machine, facing away, etc.), and using kinematic study of the reach, implementing technologies that allow knowing the relative speed between the vehicle and the person..

Once the algorithm with risk prediction capabilities is determined, the final step of the project will be integrating the developed algorithm into one of the mobile machines available at PAVASAL, incorporating warning or stopping systems on that machine in situations of accident risk.

PAVASAL would like to express its gratitude for the funding of this project through the program "Research and Development Projects on Artificial Intelligence and other Digital Technologies and their Integration in Value Chains" by the public corporate entity Red.es and the European Regional Development Fund (ERDF) "A way to make Europe".

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MINISTERIO DE ASUNTOS ECONÓMICOS Y TRANSFORMACIÓN DIGITAL
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