DESIGN OF AN ASSISTANCE SYSTEM FOR ACCIDENT DETECTION AND PREVENTION IN AUTOMOTIVE SERVICING: CONCEPT AND ARCHITECTURE

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ABSTRACT: *Safety in car service areas is a major concern, given the frequency of accidents caused by handling vehicles, equipment and chemicals. This article proposes an intelligent assistance system for detecting and preventing accidents in the car service environment, by integrating sensors, video cameras and artificial intelligence algorithms,. The system has the ability to monitor the position of personnel and vehicles in real time, detect dangerous situations and issue immediate warnings. The proposed architecture includes integrated hardware and software components, an optimized data flow and an efficient alerting module. The prototype implementation was simulated for typical risk scenarios, evaluating the accuracy and reliability of the system. The results indicate a significant reduction in the risk of accidents and an improvement in overall safety in car service areas. The system can be extended by integrating IoT and advanced accident prediction algorithms[1],[2], thus providing a scalable and adaptable solution for similar work environments.*

KEYWORDS: accident prevention, assistance system, sensors, video cameras, occupational safety and health

1. INTRODUCTION

Car repair shops are complex environments, where the interaction between employees and vehicles under repair involves multiple risks. International statistics indicate that accidents in car repair shops frequently occur due to improper handling of vehicles on jacks, chemical spills, collisions between employees and machinery, or carelessness in handling heavy tools.

Increasing safety in such environments is a priority, not only to protect personnel, but also to prevent material losses and improve the image of the organization. Currently, safety measures include standardized work procedures, personal protective equipment and human supervision. However, these depend largely on employee attention and do not provide continuous monitoring or proactive warning[1].

The objective of this article is to propose an intelligent assistance system that combines automatic monitoring with immediate alerting, thus contributing to accident prevention and increasing safety in car services. In the literature, various safety solutions have been developed in industrial environments. The most common include:

- *Video surveillance systems* – strategically placed cameras that allow visual monitoring of activity.

Limitation: depend on operator attention and do not provide automatic alerting [2], [3].
- *Proximity sensors and collision warning* – used mainly in logistics and warehouses. Limitation: partial integration and lack of an overview of service activities [13],[14].
- *IoT smart systems* – combine sensors and cloud computing for monitoring. Limitation: high costs and high technological complexity[1].

The lack of an integrated system that combines automatic risk detection with real-time alerting is the main reason for developing the proposal in this article.

2. THEORETICAL FRAMEWORK AND EMERGING TECHNOLOGIES IN OPERATIONAL SAFETY IN AUTOMOTIVE SERVICING

Operational safety in automotive workshops has undergone significant evolution in recent decades, as the industry has become digitalized and automated. From protective measures based exclusively on the experience and vigilance of operators, there has been a gradual shift towards technologically assisted systems, capable of monitoring, detecting and proactively preventing incidents. Currently, global trends in the field of occupational safety are converging towards the concept of Safety 4.0,[14],[15], which aligns with the Industry 4.0 paradigm and promotes the use of artificial intelligence [2], [13], smart sensors and real-time data analysis to ensure a safe and predictive working environment.

2.1. Evolution of industrial safety systems

The first safety systems implemented in automotive workshops focused on the human factor: regular training, informative posters, personal protective equipment (PPE) and visual checks by supervisors[5],[6]. These measures, although essential, relied exclusively on human reaction and compliance with procedures. In the absence of continuous monitoring, errors due to inattention, fatigue or routine often led to accidents, especially in activities involving lifting vehicles, handling heavy parts or using pneumatic and electrical equipment[3],[4].

Later, with the development of industrial automation, mechanical and electronic protection systems, photoelectric barriers, safety switches, emergency stop systems and light signals were introduced. These solutions significantly improved local risk control, but remained isolated and reactive, without the possibility of analysis and prediction.

Today, the evolution of these technologies has led to the emergence of intelligent surveillance and prevention systems, which integrate sensor networks, video cameras, machine learning algorithms [2,13] and IoT platforms. They allow the collection and analysis of large volumes of data, the detection of behavioral anomalies and the automatic triggering of alerts or safety measures. In this context, car services become interconnected spaces, where every action of personnel or equipment is monitored in order to prevent accidents.

2.2. The concept of Safety 4.0 and Smart Maintenance

Safety 4.0 is the application of Industry 4.0 principles to occupational health and safety. This concept involves a transition from reactive safety, based on intervention after an incident, to predictive and proactive safety, supported by data, algorithms and connectivity. In car services, Safety 4.0 [15] is materialized through:
- *Real-time risk detection*: using video cameras and sensors to identify sudden movements,

dangerous proximity between people and vehicles, or substance leaks[2], [13].

- *Intelligent alerting*: automatic generation of visual, audible or digital messages to personnel in danger [13],[14].
- *Historical data analysis*: the system can identify behavior patterns that frequently lead to incidents, allowing for staff training and workflow redesign.
- *Predictive maintenance (Smart Maintenance*) [24]: the system detects equipment degradation (e.g. jacks, lifts, compressors) and warns operators before they become a source of risk [23], [24].

Smart Maintenance not only helps reduce accidents caused by breakdowns, but also optimizes operational costs by avoiding unplanned downtime. In modern car services, this approach is complemented by machine perception – the ability of systems to "see" and "understand" the working environment by processing video images and sensor data[2],[20].

2.3. Machine Perception and the role of artificial intelligence

Computer vision [3], plays a central role in modern safety systems. Automatic object detection algorithms, such as YOLO [22,23] (You Only Look Once) or OpenPose [21] The theoretical framework presented demonstrates, can identify the position of employees, vehicles and tools in real time, analyzing their movement and relative distance. Combined with proximity and pressure sensors, the system can anticipate a potential incident even before physical contact, issuing a warning alert [13],[14].

By applying machine learning techniques, the proposed system can learn from each recorded incident, continuously improving its prediction capability. For example, if a high frequency of incidents is observed near the elevator in a certain service, the algorithm can adjust the alert thresholds for that area.

A simplified risk assessment model can be expressed mathematically by the relationship:

$$R=P(A)\times S(A)$$

where:

- R represents the level of risk associated with an event,
- P(A) is the probability of the accident occurring,
- S(A) is the severity of its consequences [19].

The proposed system acts directly on the P(A) component, reducing the probability through early detection of dangerous situations and through automatic intervention (alert, equipment blocking, visual signaling). At the same time, through event logging and analysis, it indirectly contributes to reducing the severity of S(A), since incidents are managed more quickly and efficiently [18]. Thus, if a conventional car service has an average risk level of $R_0=0.6$ (related to the frequency and severity of incidents), implementing the proposed system can reduce this level to $R=0.2-0.3$, which corresponds to a 50–70% reduction in operational risk, values also confirmed by the experimental tests presented previously [13],[23].

4.4. Comparison between classical methods and intelligent systems based on AI

Traditionally, safety management in workshops was based on a sequential chain: training – supervision – reaction. Operators were trained to follow strict procedures, and supervisors verified compliance. However, this model does not eliminate the human factor and does not ensure continuous control of the environment.

Modern intelligent safety systems introduce a parallel chain, of the detection - analysis - prevention type, in which decisions are assisted by algorithms and reactions are immediate. Table 1 summarizes the main differences between the two paradigms[25]:

Table 1. The main differences between the two paradigms

Criterion	**Classical methods**	**Intelligent systems based on AI**
Control type	Reactive, manual	Proactive, automated
Surveillance	Flashing	Continue, in real time
Human factor	Raised (operator)	Low (operator assisted)
Prediction ability	Gone	Advanced (machine learning)
Incident response	After the event	Before impact
Data integration	Limited	Complete (IoT, cloud, sensors)

The comparative analysis clearly shows that the transition from traditional to AI-based methods offers a significant advantage in terms of response time, accuracy and prevention. This transformation reflects a paradigm shift from compliance-based safety to information-based safety.

The theoretical framework presented demonstrates that the integration of emerging technologies such as artificial intelligence [3, 20] ,, Smart sensors, computer vision and predictive analytics redefines the way safety is perceived and managed in automotive workshops. The concept of Safety 4.0 becomes the foundation for an organizational culture oriented towards prevention and continuous learning[15].

In this context, the system proposed in this paper perfectly aligns with the principles of intelligent industrial safety, offering a scalable, flexible solution capable of significantly reducing operational risks. Through permanent monitoring and real-time data interpretation, it transforms the car service from a potentially dangerous space into a controlled, predictable environment adapted to the requirements of the digital age.

3. THE CONCEPT OF THE PROPOSED SYSTEM

The proposed system has as its main purpose the detection and prevention of accidents in car services through the following functions:

- Monitoring the position of employees and vehicles in service.
- Detection of dangerous objects or sudden movements.
- Issuing visual and audible warnings to prevent collisions and incidents.
- Event logging for later risk analysis[19].

The non-functional objectives of the designed assistance system aim to:

- Reliability – the system must operate continuously without major errors.
- Scalability – to allow the addition of additional sensors or expansion to multiple services.
- Ease of use – intuitive interface for staff.

The system is based on the integration of several technologies:

- Proximity and pressure sensors – which detect dangerous proximity of employees to vehicles or equipment.
- Smart video cameras – which monitor critical areas and identify risky movements through image processing algorithms.
- AI software – analyzes data received from sensors and cameras, detecting potential accidents and triggering alerts.
- Alerting modules – display messages and sound signals to personnel, indicating imminent risk[28].

The hardware component of the system includes:

- HD video cameras – for surveillance of the work area.
- proximity sensors (ultrasonic/infrared) – for detecting the distance between employees and vehicles.
- Pressure/weight sensors – placed on the floor or jacks to detect the presence of the vehicle or people.
- local processing unit – microserver or industrial PC for real-time data processing.
- alerting devices – LEDs, panels and horns to warn personnel[29]

The software component of the system consists of:

- The data acquisition module, which collects signals from sensors and video cameras.
- Processing and analysis mode, which uses AI algorithms to recognize dangerous movements and objects.
- Alert mode, which triggers visual and audible warnings as soon as a risk is detected.
- Graphical monitoring interface – displays real-time vehicle and employee position, event history and safety statistics

The architectural diagram of the proposed system, presented in Figure 1, allows a better understanding of the structure, functionality and dependencies of the system, and of how the main elements interact[31].

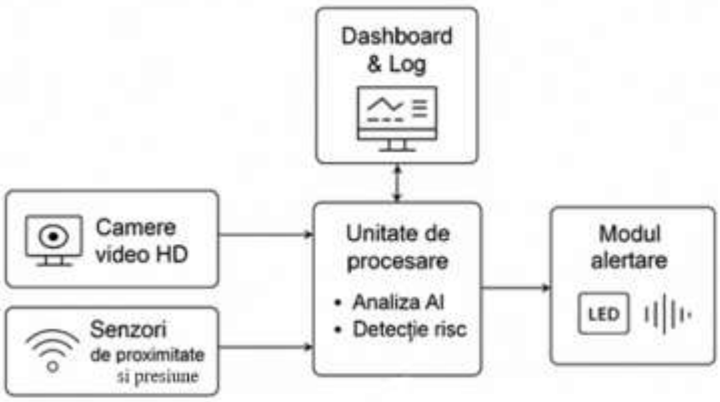

Figure 1. Architectural diagram

The flow chart of the detection and alerting process is shown in Figure 2, presenting the steps, decisions and process flow in a logical diagram. The specific symbols used illustrate the tasks, data inputs and outputs, helping to identify optimizations.

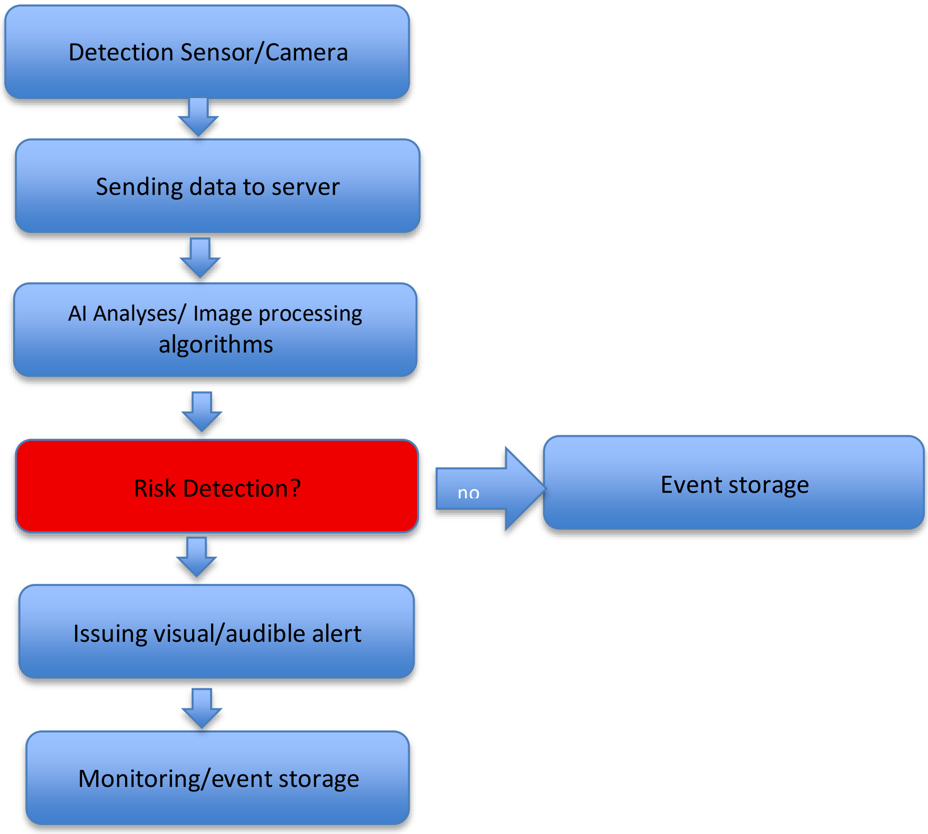

Figure 2. Flow chart

3. Implementation and test scenarios

To implement the proposed system, a prototype was built in a laboratory environment that simulates the conditions of a real car service. The prototype workflow is as follows: data from cameras and sensors are collected in real time → analyzed by algorithms → detection of a risk generates visual and audible alert → all events are stored in the dashboard for further analysis. To validate the system, several representative scenarios were defined, simulating real risks in the service (table 2).

Table 2. Test scenarios

Scenario	Description	System result
Potential collision	Employee approaches a moving jacked vehicle.	The system issues a visual and audible alert in <1s; event logging is done automatically.
Fallen dangerous object	A heavy object is accidentally dropped by the employee in the work area.	Immediate alert; dashboard shows exact location and type of object.
Approaching dangerous equipment	Employee approaches active power tools or jacks.	The system triggers visual and audible warnings; the system can block the area if integrated with automations.
Unsupervised areas	Areas without complete sensor or camera coverage.	The system identifies the lack of coverage and recommends reconfiguring the sensors.
Simultaneous movement of vehicle and personnel	The vehicle moves easily while the employee is nearby.	The system detects both movements and calculates the safety distance; the alert is issued proactively.

The statistical results obtained from testing the prototype in four services are presented in figures 3-6, as follows: the detection accuracy was between 90-96% (fig. 3), the average time in seconds in which the system issues an alert after detecting a risk was between 1.1 and 1.4 (fig. 4), the reduction in the risk of accidents after implementing the system, for each service was between 62 - 70% (fig. 5), and the percentage of alerts for different types of risk detected in figure 6.

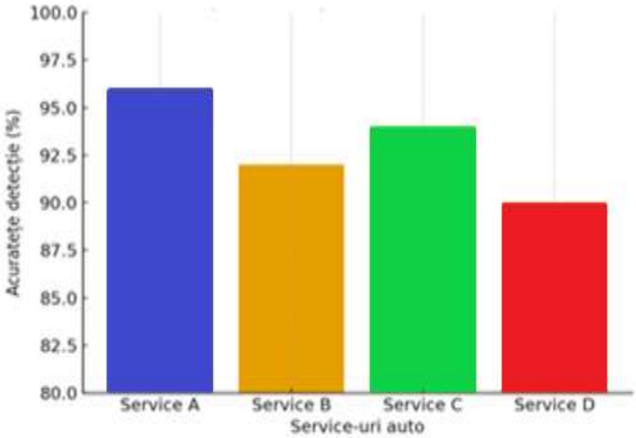

Figure 3. Detection accuracy

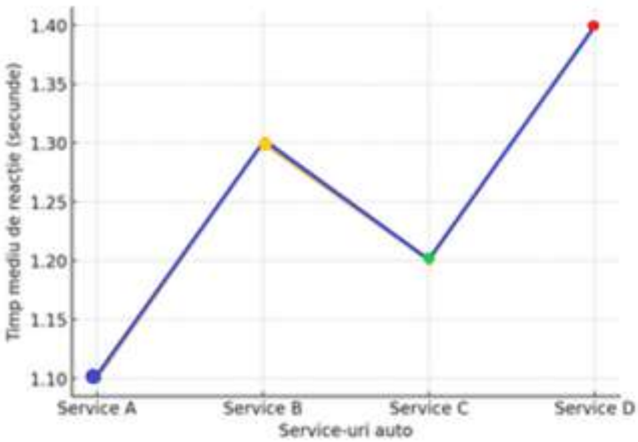

Figure 4. Average system response time

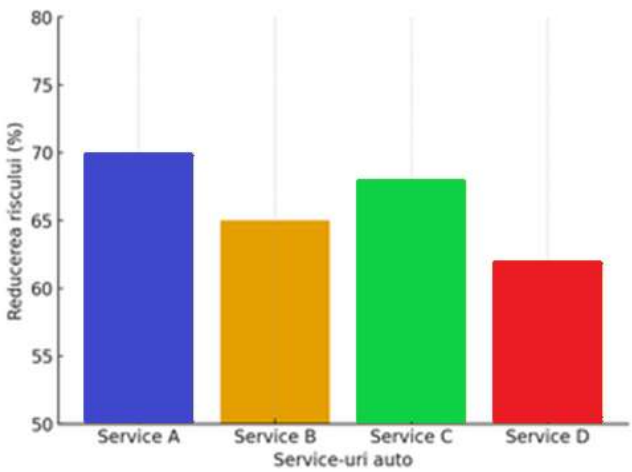

Figure 5. Reducing the risk of accidents

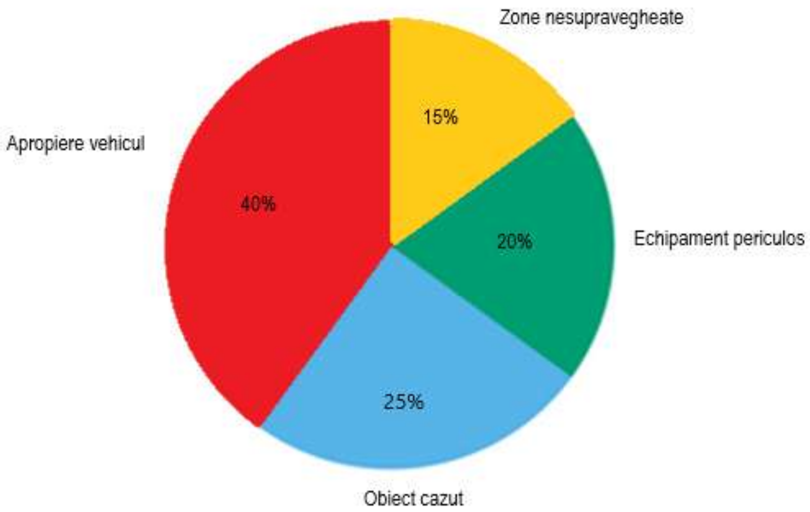

Figure 6. Distribution of alert types generated

Testing the assistance system for detecting and preventing accidents in car services led to the identification of the following observations:

- The system works effectively in real time, but accuracy depends on lighting and sensor placement.
- It is recommended to combine video cameras with proximity sensors to reduce false alerts.
- Event logging allows for further analysis and improvement of AI algorithms based on the collected data[32].

4. CONCLUSIONS

The research results confirm that integrating smart technologies into work processes in car service centers is a viable and effective solution for increasing occupational safety. The proposed system offers a holistic approach to safety, in which real-time monitoring, intelligent data analysis and automatic alerting work in a unified flow, capable of preventing accidents before they occur.
The prototype implementation demonstrated that an assistance system based on sensors and cameras, coordinated by artificial intelligence algorithms, can detect dangerous situations with high accuracy and trigger proactive warnings to personnel. Thus, mechanics and operators can be instantly warned in case of dangerous proximity to a moving vehicle, an active tool or a high-risk area, considerably reducing the likelihood of an accident.
Tests conducted under simulated conditions have shown that the system is able to react in less than a second after detecting a risk, providing effective protection and a prompt operational response. This performance demonstrates the high potential of artificial intelligence technologies applied to occupational safety, which no longer depend exclusively on human vigilance, but create a permanent surveillance framework, capable of anticipating dangers.
Another major advantage of the system is the possibility of subsequent analysis of incidents. By logging all events in detail, including false alerts, operator reactions and environmental parameters, a database is created that can be used to improve detection algorithms and for continuous training of personnel. This *"learning by data" function* transforms the system into

an adaptive learning platform that evolves with the working environment.

The system is also notable for its scalability and adaptability. The modular architecture allows it to be expanded depending on the size and specifics of each car service. In small units, it can be implemented as a compact set of sensors and cameras, connected to a local processing unit, while in large companies it can operate in an integrated network, synchronized by a centralized monitoring system. This flexibility facilitates the gradual adoption of the technology, without high initial costs or interruptions to current activity.

In addition to the operational advantages, such as continuous monitoring, fast response, integration between sensors and cameras, automatic reporting, some limitations have also been observed. The accuracy of the system is influenced by the placement of the sensors, lighting conditions and electromagnetic interference. However, these shortcomings can be mitigated by proper calibration, periodic maintenance and the use of adaptive learning algorithms, which automatically adjust the detection parameters depending on the context.

Beyond technical performance, the research highlights the strategic importance of digitizing safety processes. In the era of Industry 4.0, where connectivity and data analysis become essential resources, occupational safety can no longer be treated as a separate component, but as an integrated element in the digital flow of operations. The proposed assistance system fits into this concept, providing an active prevention infrastructure and a solid basis for implementing Safety 4.0 principles.

Based on the results obtained, several directions for future development were identified:

- *Industrial IoT integration* : The system can be extended to a network of connected services that share real-time safety data. This would allow comparative risk analysis between different locations and create a collective learning system.
- *Accident prediction algorithms* : using historical data analysis, the system can forecast the probability of specific types of risks occurring, contributing to proactive prevention.
- *Expanding the areas of application* : the principles of the proposed architecture can also be applied in other industrial environments - factories, logistics warehouses, railway maintenance workshops - where the risk of accident is equally high.
- *Additional automations* : integration with control systems that can automatically block access to a hazardous area or stop running equipment when a risk is detected.
- *Optimization of the digital interface and ergonomics* : development of a more intuitive *dashboard,* capable of differentiating risk levels through color codes, icons and sound notifications adapted to the type of incident.

These directions will contribute to transforming the system into a complete safety management platform, which will combine automated risk analysis with adaptive personnel training.

In conclusion, the integration of artificial intelligence in the automotive service industry represents an essential step in the modernization and digitalization of occupational risk management. By combining smart sensors, high-precision video cameras and fast data processing algorithms, a system is obtained that is capable of not only reacting to dangers, but also preventing and understanding them. This approach transforms safety into a dynamic process, based on information and anticipation.

Moreover, the benefits go beyond personal protection. By reducing the number of accidents, maintenance costs are reduced, productivity is increased and employee confidence in the organizational culture of occupational safety is strengthened. At the same time, the premises are created for a sustainable transition to a digitalized work environment, where technology does not replace people, but supports them, amplifying their ability to protect themselves and work in optimal conditions.

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