POLITECNICO DI TORINO

Master's degree course in Computer Engineering

Master's thesis

# Safety systems for the control and prevention of accidents at work

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**Abstract**

This thesis, made possible thanks to the support of ARES (ENGINEERING for HEALTH and SAFETY, ENVIRONMENT,WELL-BEING and SUSTAINABILITY), presents the A101 device, an innovative security sensor designed for the specific detection of people within monitored areas. Unlike devices currently available on the market, such as the safeVisionary2 produced by SICK, which detect any object entering the ROI (Region of Interest), the A101 stands out for its ability to identify and report exclusively human presence. The A101 is based on a combination of several technologies, including imaging processing, artificial intelligence and ROI analysis. This synergy allows real-time monitoring of critical areas and the identification of potentially dangerous situations, significantly improving operator safety and the protection of industrial machines. Furthermore, this thesis shows how the device has been designed to comply with rigorous safety standards, including the performance requirements of Type 2, SIL1 according to IEC 61508 and PLc according to EN ISO 13849-1, ensuring its operation in critical industrial environments for safety. It is important to underline that the A101 is still under development and does not represent its final form. Further future developments include the implementation of three-dimensional ROIs and the integration of TOF cameras for greater accuracy and reliability.

# Contents

# Chapter 1

# Introduction

Work, as enshrined in the Italian Constitution, is a fundamental right that plays a crucial role in personal development and social progress. However, protecting health and safety on the job is a primary ethical and legal imperative. Despite the existence of regulations and safety measures, the number of accidents at work, including fatal ones, remains alarming, even in technologically advanced environments. This thesis focuses on safety in industrial environments that are characterized by the presence of complex machinery, complex production processes, and a variety of potential hazards. Industrial environments, in fact, present unique challenges in terms of safety, due to the nature of the operations performed and the variety of equipment used. The main objective of this work is to present the A101 device, an innovative safety sensor currently in development, designed to detect the presence of people within the monitored areas. The A101 device is proposed as an important tool to improve operator safety and the protection of industrial machines. The operation of the A101 device is based on a synergy of advanced technologies, including image processing, artificial intelligence, and ROI (Region of Interest) analysis. This combination of technologies allows real-time monitoring of critical areas and identification of potential dangerous situations. The thesis illustrates the software architecture of the A101 device, which includes:

- **A configurator:** a software application that allows users to customize warning and alarm areas. This tool is essential to adapt the device to the specific needs of each work environment, allowing flexible and targeted security management;

- **An internal server:** responsible for acquiring and processing images from the integrated cameras, as well as managing the database and communications with the configurator. The internal server represents the heart of the system, ensuring that the collected data is processed efficiently and that critical information is readily available to operators;

- **An artificial intelligence module:** based on the MediaPipe library, this module is able to detect key points of the human body in real time, analyzing video streams from the cameras. The use of artificial intelligence allows the device to quickly and accurately recognize dangerous situations, significantly improving the system's responsiveness;

The purpose of the thesis is to demonstrate the effectiveness of the A101 device in preventing accidents at work, analyzing its functionality, performance, and potential. The importance of compliance with safety regulations, such as EN ISO 13849-1 and CEI EN 61508-1, will also be highlighted to ensure the reliability of the device in safety-critical industrial environments. Compliance with these regulations not only ensures that the device meets international safety standards but also contributes to creating a safer and more protected working environment for all involved operators. In conclusion, the A101 device represents a significant step forward in industrial safety technology. Its ability to integrate several advanced technologies to monitor and protect work environments makes it an indispensable tool for companies seeking to improve safety and operational efficiency. The thesis not only explores the technical characteristics of the device, but also underlines the importance of a proactive approach to workplace safety, highlighting how technological innovation can contribute to significantly reduce the risk of accidents and promote a safer and more sustainable working environment.

# Chapter 2

# Background

Work is universally recognized as one of the essential elements for the fulfillment of the individual. In fact, each person shows a natural and unique predisposition towards specific types of work activity, which represent not only a source of income, but also a fundamental dimension for growth and psychophysical well-being. The Italian Constitution, in defining work as a fundamental right, underlines its primary role both for the individual and for the community, recognizing it as an activity oriented towards material and social progress. In this context, however, it is necessary to focus attention on another crucial and highly topical aspect: the protection of health and safety in the workplace. In fact, the Constitution is not limited to guaranteeing the right to work, but is also configured as a tool for promoting the health and safety of workers, orienting the entire body of regulations and legislation on the matter. The protection of health and safety in the workplace is not only a legal issue, but an essential ethical value, which is configured as a priority objective in labor policies both at European and national level. Despite the issuing of numerous legislative decrees that regulate in detail the obligations and protection measures to be adopted in work contexts, the current situation continues not to reflect the most optimistic expectations. The phenomenon of accidents at work, even with fatal outcomes (the so-called "white deaths"), persists to a worrying extent. This situation occurs, paradoxically, even in work environments characterized by high technologies and severe and complex legislative regulation. This work will focus in particular on a work context within an industrial plant, where the risks of accidents are high due to various factors, such as the length of shifts, extreme temperatures, or the lack of adequate prevention measures.

## 2.1 Industrial environment

According to Treccani, in an industrial context, a factory means «*building or complex of buildings shaped and equipped for the manufacture and processing of certain products*». Any industrial process uses raw materials that are transformed to obtain the final product. The transformation of raw materials may include assembly processes of components, followed or not by installation phases of the product in the destination or use environment. It is important to consider that the use of these machines by workers can lead, for various reasons, to the risk of accidents. For this reason, workers must be adequately trained and the machines must be designed to be safe. Industrial environments may vary depending on the sector and the specific production activity, but they have some common characteristics that significantly influence work dynamics and safety needs:

- **Automation:** The use of automated machinery and robots is now a consolidated practice in industrial environments. This automation allows for improved efficiency, precision and speed of production processes. However, human-machine interaction involves risks that must be managed through adequate safety measures. For example, industrial robots, if not managed correctly, can pose a threat to operators, which is why physical barriers and rigorous safety protocols are necessary;

- **Complex Production Processes:** Industrial manufacturing often involves chemical, physical and mechanical processes. These processes require constant monitoring and precise management to ensure that operating parameters are met and any anomalies are detected and corrected promptly. The adoption of advanced control systems and the implementation of real-time monitoring technologies are essential to maintaining the safety and efficiency of production processes;
- **Dynamic Environments:** Industrial environments must be able to adapt quickly to changes in production and market demands. This dynamism requires operational flexibility that must be balanced with rigorous safety standards. Adopting lean manufacturing practices allows you to respond effectively to changes in demand while maintaining a high level of safety.

According to Legislative Decree 81/08, risk assessment in industrial plants is an obligation for all employers, aimed at ensuring the safety and health of workers. In industrial plants, different types of hazards can occur, each of which requires specific management and prevention measures. Hazards can be classified into various categories, each with particular implications for worker safety:

- **Mechanical hazards:** These include slipping, tripping, falling, impacting and crushing hazards. These hazards are often associated with the use of heavy machinery and equipment;
- **Electrical hazards:** They concern risks of fire, electrocution, electrocution and burning;
- **Thermal hazards:** These include burning, scalding, and freezing hazards. These hazards are common in processes involving high or low temperatures, such as metalworking and food preservation;

- **Noise-generated hazards:** Prolonged exposure to high levels of noise can cause permanent hearing loss, ringing in the ears, tiredness and stress;
- **Vibration hazards:** They include fatigue, lumbar spine disorders, spinal trauma, Raynaud's phenomenon, and neurological disorders;
- **Radiation hazards:** Exposure to radiation can cause genetic mutations, insomnia, migraines and reproductive effects;
- **Chemical hazards:** Includes risk of chemical burns, suffocation, fire and explosion;
- **Dangers arising from failure to observe ergonomic principles:** They include fatigue, musculoskeletal disorders, vision problems and stress;

The implementation of advanced safety devices, such as the A101, can significantly contribute to reducing risks and improving worker protection. The A101, with its real-time monitoring and danger area detection capabilities, represents a major innovation for safety in industrial environments. The technologies integrated into the A101 allow for the detection and analysis of various types of dangers that may arise in an industrial environment. These technologies include image processing, artificial intelligence, and ROI (Region of Interest) analysis, which together ensure constant and accurate monitoring of critical areas. This allows for the immediate identification of any anomaly or potentially dangerous situation, consequently activating appropriate alarms and safety protocols. The following table shows the main risks that the A101 can prevent:

| hazard | A101 Prevents |
|---|---|
| mechanical | YES |
| electrical | YES |
| thermal | YES |
| noise | NO |
| vibration | NO |
| radiation | NO |
| chemical | NO |
| ergonomic | NO |

## 2.2 Regulations

Safety regulations in the field of industrial machinery are divided into 3 categories:

- **Type A:** They concern the basic concepts and design principles;
- **Type B:** They deal with several aspects of safety and means of protection for a large number of machines. This category has a further internal subdivision:
  - **Type B1:** They deal with distances, surface temperatures and noise;
  - **Type B2:** They deal with protection systems;
- **Type C:** They deal with multiple aspects of safety and protection means for a limited number of machines;

### 2.2.1 EN ISO 13849-1

EN ISO 13849-1 (Type B1 as specified by *ISO 12100*) is one of the main standards describing the Performance Levels (PL) applicable to safety devices in industrial applications. This standard is essential to ensure that safety-related control systems, including those based on electrical, electronic and programmable components, are adequately designed and operated to mitigate the risks associated with industrial operations.

**Performance Level**

Performance Level (PL) is a qualitative measure of the level of reliability of a safety system. It is expressed in five levels, from PLa to PLe, with PLe representing the highest level of reliability. Each level is defined in terms of probability of dangerous failure per hour (PFHd). Currently, the project goal is to achieve at least level C, although the long-term aspiration would be to reach level D. This involves a rigorous design, implementation and verification process to ensure that the safety system effectively meets regulatory and operational requirements.

| PL | Probabilità media di guasto pericoloso per ora ($PFH_D$) 1/h |
|---|---|
| a | $\geq 10^{-5}$ fino a $< 10^{-4}$ |
| b | $\geq 3 \times 10^{-6}$ fino a $< 10^{-5}$ |
| c | $\geq 10^{-6}$ fino a $< 3 \times 10^{-6}$ |
| d | $\geq 10^{-7}$ fino a $< 10^{-6}$ |
| e | $\geq 10^{-8}$ fino a $< 10^{-7}$ |

**Figure 2.1:** Performance Levels

### 2.2.2 CEI EN 61508-1

IEC 61508-1 is an international standard that provides a generic framework for ensuring the safety of electrical, electronic and programmable logic controllers (E/E/PE). This standard is particularly important for assessing the integrity of safety functions through the Safety Integrity Level (SIL).

**Safety Integrity Level (SIL)**

The Safety Integrity Level (SIL) is a quantitative measure of the reliability of a safety system, and is divided into four levels, from SIL1 to SIL4, with SIL4 representing the highest level of integrity and reliability. For the project in question, the objective is to achieve SIL 1, equivalent to PLc as described above.

| Safety integrity level<br>(SIL) | Average frequency of a dangerous failure of the safety function [$h^{-1}$]<br>(PFH) |
|---|---|
| 4 | $\geq 10^{-9}$ to $< 10^{-8}$ |
| 3 | $\geq 10^{-8}$ to $< 10^{-7}$ |
| 2 | $\geq 10^{-7}$ to $< 10^{-6}$ |
| 1 | $\geq 10^{-6}$ to $< 10^{-5}$ |

**Figure 2.2:** Safety Integrity Level

### 2.2.3 IEC 61496-3 §A.9.*

IEC 61496-3 §A.9.* specifies that security device configuration software must include a secure access system. This requirement is essential to prevent unauthorized access and unintentional changes that could compromise security. A secure access system ensures that only authorized users can access and change security system settings. This includes implementing password-based access controls.

### 2.2.4 UNI EN ISO 13855

The UNI EN ISO 13855 standard establishes the stopping distances and times required to calculate the minimum size of the ROI. This standard is crucial to ensure that safety zones are correctly sized, taking into account human reaction times and the stopping characteristics of the machines.

## 2.3 Hardware used

In this section, a comprehensive overview of the hardware currently used in the A101 prototype device and a description of the final hardware planned for the finished product will be presented. The reasons why the final hardware implementation has not yet been achieved will also be discussed, highlighting the difficulties encountered in following the regulations necessary to obtain the CE mark.

### 2.3.1 Prototype Hardware (Current Hardware)

Currently, the device is based on the hardware used during the prototype development phase. This hardware has allowed us to test and validate the key concepts and functionalities of the system.

- **Personal PC**
- **Integrated Camera in PC**

This configuration, although limited, allowed us to establish the basis of the device's operation.

### 2.3.2 Final Hardware

The move to final hardware will bring a number of significant optimizations and improvements to increase performance, security, and overall device functionality.

- **NUC:** The heart of the system will be a small-scale computer (NUC), which will perform all data processing operations;
- **2 x TOF Cameras:** These imaging devices will provide both RGB data (color images) and depth data (depth maps), thanks to the use of

TOF technology. TOF cameras will significantly improve the accuracy of people detection and tracking capabilities. TOF technology measures the time it takes for light to reflect off objects and return to the sensor, allowing for detailed and accurate mapping of distances;

- **Thermal Camera:** This sensor will be integrated to provide a third level of control;
- **I/O Safety Board:** A hardware interface that will receive commands from the NUC and activate OSSD outputs, compliant with *IEC 61508* safety standards.

One of the main reasons why the final hardware has not yet been implemented is the difficulty in obtaining the necessary components to obtain the CE mark. The regulations are extremely strict and require that all components of the device meet specific safety standards.

# Chapter 3

# Proposed approach

## 3.1 Software architecture

### 3.1.1 Configurator

The A101 device configurator is a software application designed to provide users with an intuitive interface, which facilitates the configuration and customization of warning and alarm areas. This tool manages the acquisition and processing of images from the integrated cameras, activating specific routines when it detects the presence of people thanks to an artificial intelligence module. It is important to note that the image processing is performed by an internal server. The configurator is structured into different pages and sections, each of which is dedicated to a specific function. The configurator interface is designed to be user-friendly, with clear menus and accessible features, ensuring that even less experienced users can use it effectively. This intuitive design reduces the time required for user training and minimizes operational errors, contributing to more effective management of the A101 device.

### 3.1.2 Internal Server

The internal server of the A101 device is the beating heart of the system, responsible for managing all data and critical operations. The main components and features of the internal server are described below.

- **Communication Interface:** This interface manages all communications between the configurator and the server, using the HTTP request system. It ensures a secure and stable connection, allowing the exchange of data in real time between the various components of the system;
- **Image Processing Module:** Responsible for the acquisition and processing of images from the integrated cameras. This module uses advanced computer vision algorithms to analyze video streams in real time, detecting the presence of people or parts of them. The ability to process visual data quickly and accurately is essential to ensure the safety and effectiveness of the system;
- **Artificial Intelligence Module:** The machine learning algorithm used is a pre-trained model called Mediapipe;
- **Database:** The server database stores all system configurations, user information, and other critical data. It is designed to provide fast and secure access to information, supporting efficient read and write operations.(Figure 3.1)

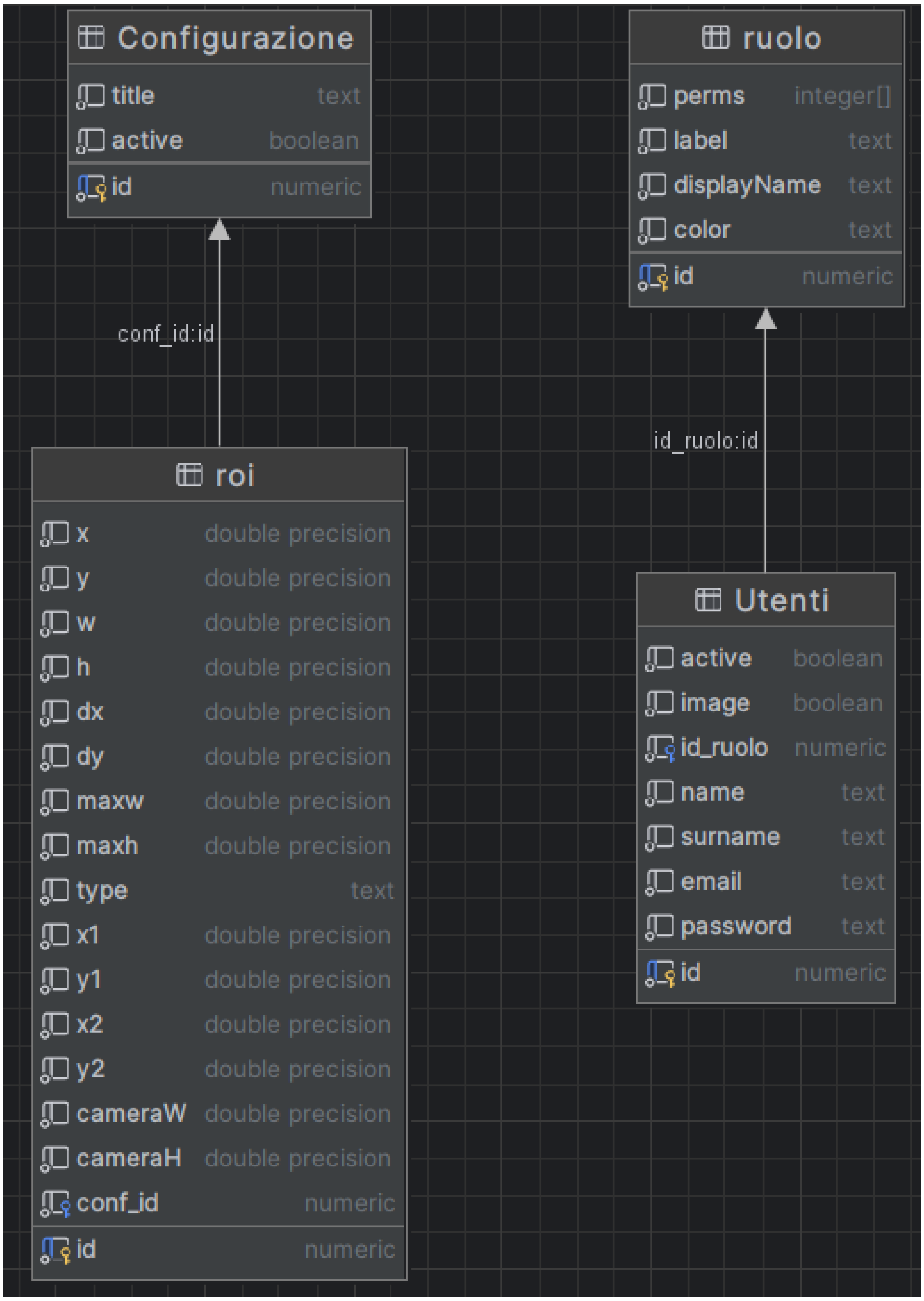


**Figure 3.1:** Database

### 3.1.3 Artificial Intelligence Module

As mentioned in the previous paragraph, the algorithm used is MediaPipe, an advanced library that provides tools for real-time extraction of human body keypoints for each frame, as illustrated in Figure 3.2. This library provides various information for each keypoint, including spatial coordinates (x, y), which are essential for analyzing motion and position. MediaPipe can identify the positions of joints and other body parts, such as the head, shoulders, elbows, wrists, hips, knees and ankles. The coordinates extracted from the keypoints were mapped in the same reference system as the ROIs (Regions of Interest), ensuring an exact correspondence between the detected data and the areas of interest defined by the users. Once mapped, the coordinates are used to perform an in-depth analysis, checking whether at least one keypoint is located within a ROI. If a key point is detected within a ROI, the system activates a specific routine based on the ROI type. There are two main types of ROI in the system: Alarm ROI and Warning ROI. When a key point enters a Warning ROI, the system can generate a warning or perform a series of preventive actions to ensure the safety of the monitored area. If the key point enters an Alarm ROI, the system can perform more immediate and critical actions.

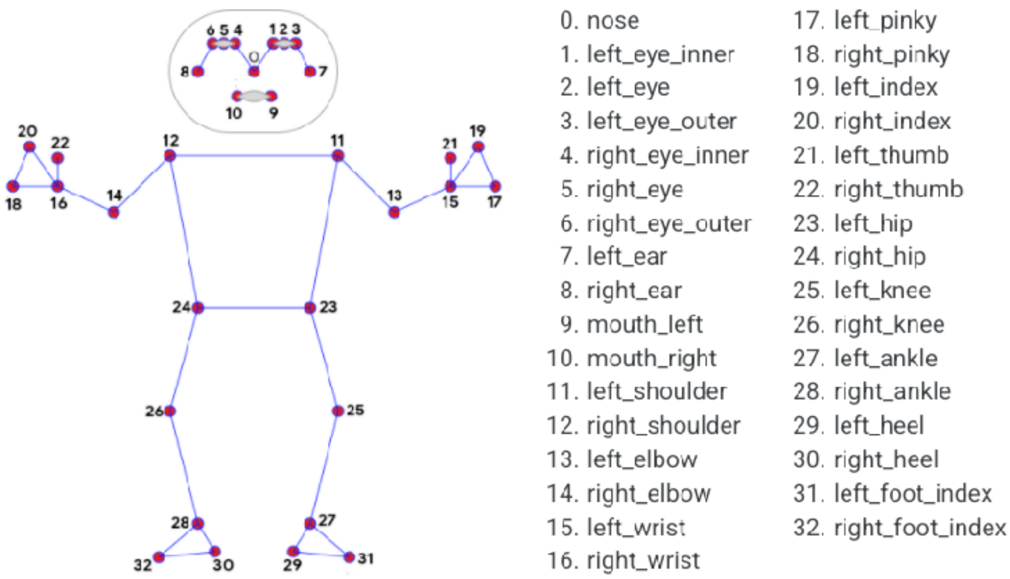


**Figure 3.2:** Mediapipe Key Points

Despite the many advantages that MediaPipe offers, there are some limitations to consider. One of the main limitations is that the algorithm can only track landmarks for a single individual in the frame. To address this issue, two options have been explored:

- **Performing Object Detection of People Using YOLO and Applying MediaPipe to Each Detected Bounding Box:** This approach involves using an object detection model, such as YOLO (You Only Look Once), to detect people in the frame. Then, MediaPipe is applied to each detected bounding box to track key points. However, during testing, this method dropped the frame rate (FPS) to 2, making the system impractical. With more performant hardware, this approach may become feasible;
- **Abandon MediaPipe and Use Segmentation Also Using YOLO:** Another solution explored was using segmentation with YOLO, which showed a more acceptable frame rate (FPS = 15). This approach was

considered more feasible and may be integrated into future system updates.

## 3.2 Application

### 3.2.1 Login page

The first screen visible when opening the application is the login page, where users can authenticate by entering their credentials. This screen has been carefully designed to ensure an intuitive and secure user experience. There are mainly two types of users with different levels of access and functionality:

- **Administrator/Superuser:** This user type has full access to all the features of the application. This includes user management, role management, manipulation of configuration ROIs, viewing logs, and access to a message box.
- **User:** Standard users have access to a limited number of features, which can vary based on the administrator's decisions. These users can be further divided into categories, depending on the specific needs and permissions set by the administrator.

Authentication is mandatory as per *IEC 61496-3 §A.9.**

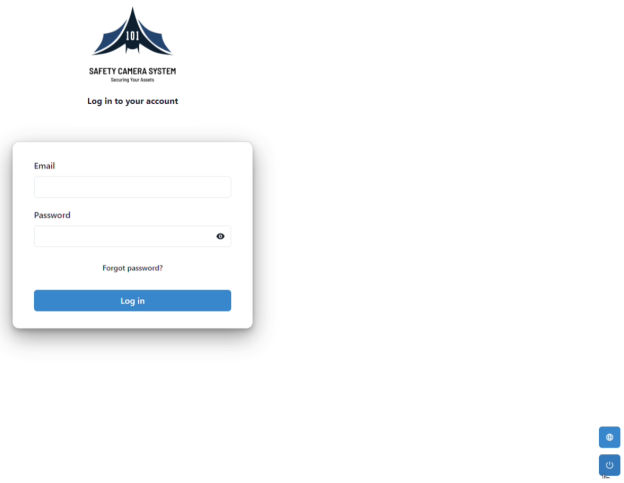


**Figure 3.3:** Login Page

**A.9.1 Functional requirements**

The setting of the detection zone and/or other safety-related parameters shall not be possible without using a key, keyword or tool.

NOTE For example, the tool can be a password protected software configuration program that is a part of the ESPE.

If the setting is carried out using a personal computer or equivalent fitted with untested dedicated hardware and/or software, a special procedure shall be used for setting the detection zone. This procedure shall be in accordance with appropriate standards (see also 4.2.11). If the tool is software, only software authorized by the supplier shall be used.

The setting of safety-related parameters should only be performed by qualified persons. The procedure shall include measures to ensure that the input parameters are transmitted correctly and without corruption to the ESPE. This shall be applied for all safety-related settings, for example, the setting of the response time. The parameterization procedures shall conform to an appropriate standard (e.g. IEC 62061:2005, 6.11.2, or ISO 13849-1:2015, 4.6.4).

**Figure 3.4:** IEC 61496-3 §A.9.*

As you can see from Fig. 3.3, the login page also offers additional features to improve the user experience. Among these, there is the possibility to recover the password in case of loss and to change the interface language via a convenient button located at the bottom right. Currently, the available languages are Italian and English, making the application accessible to a wider range of users.

### 3.2.2 Admin - User Management Page

With an Admin account, you can access the user management page, a fundamental section for the administration of the platform. This page offers a detailed overview of the list of users, including essential information such as username, role, email address and account status. Viewing this information allows administrators to effectively monitor user activity and ensure that each account is properly managed. For each user, the Admin has the ability to perform several operations:

- **Edit:** This function allows you to update the details of the selected account, allowing changes such as name, role and other relevant data, ensuring that the information is always correct and up to date;
- **Delete:** Using this option, you can remove the selected account from the system. This function is particularly useful for managing obsolete or no longer needed accounts, thus keeping the platform clean and organized;
- **Disable/Enable:** Allows you to temporarily deactivate an account, preventing access to the user without having to permanently delete it.This function is useful for suspending accounts in case of need for review or to manage periods of inactivity;
- **Reset Password:** This function allows you to change the user's password, either manually, by entering a new specific password, or automatically, by generating a random password (Fig. 3.7);

In addition to these features, the administrator has the ability to add new users via a button located at the top right of the page (Fig. 3.6). This allows for flexible and dynamic management of users, facilitating the expansion and customization of access to the various resources of the platform.

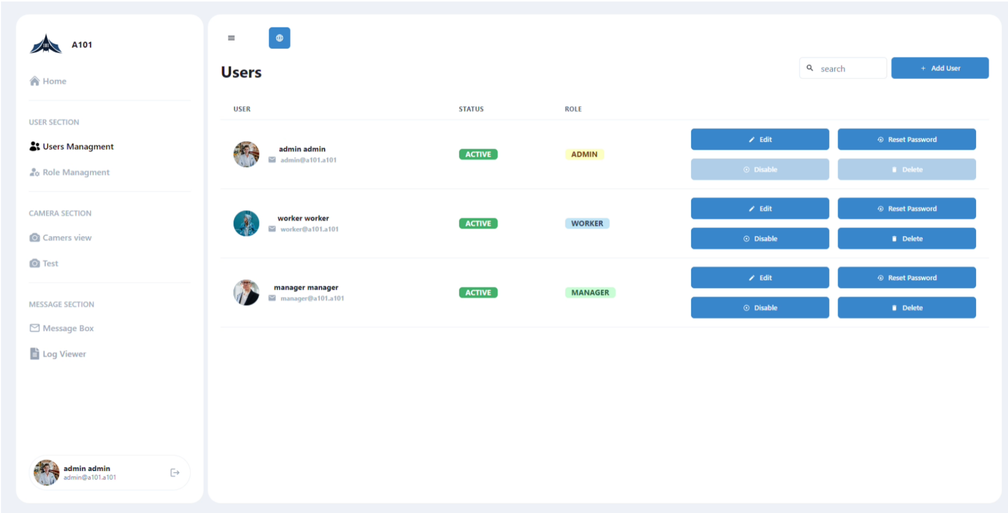


**Figure 3.5:** User management page

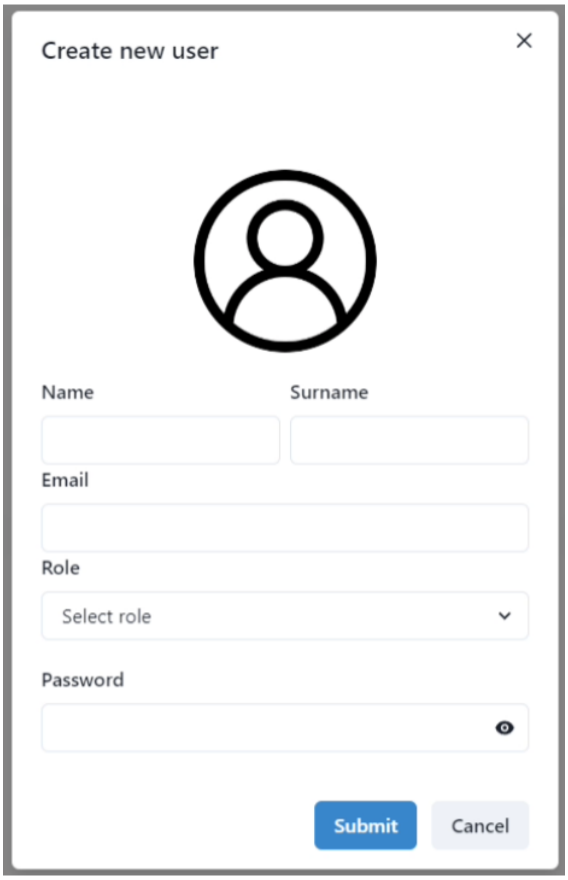


**Figure 3.6:** User Creation

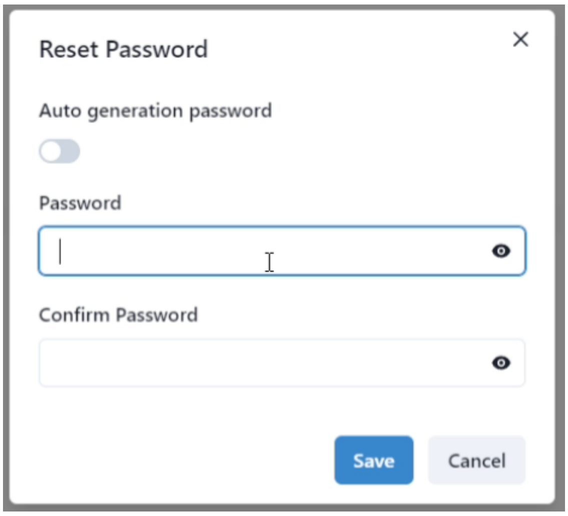


**Figure 3.7:** Reset Password

### 3.2.3 Admin - Role Management Page

Always with an Admin account you can access the role management page, shown in Fig. 3.8. This page offers a complete view of the list of roles present in the platform, associated with a series of checkboxes that indicate the permissions assigned to each role. This structure allows the administrator to have precise control over the permissions of each role, improving the security and organization of the entire system. Possible operations include:

- **Edit:** This feature allows you to update the information related to the selected role. The administrator can change the name of the role, add or remove specific permissions;
- **Delete:** This option allows you to completely remove the selected role from the system. It is a useful function to keep the list of roles clean and updated, eliminating those that are no longer necessary or relevant;
- **Add Role:** In addition to the edit and delete options, the administrator has the ability to add new roles. This is done via a button located at the top right of the page, as shown in Fig. 3.9. This feature is essential to

ensure flexibility in user management, allowing the creation of custom roles that meet the specific needs of the organization.

The role management page is designed to be intuitive and easy to use, ensuring that the administrator can make quick and effective changes. The ability to clearly view the permissions associated with each role makes it easy to assign the right permissions, avoiding mistakes that could compromise the security of the system. In this way, role management becomes a simple, yet powerful, process to maintain control over access and operations within the platform.

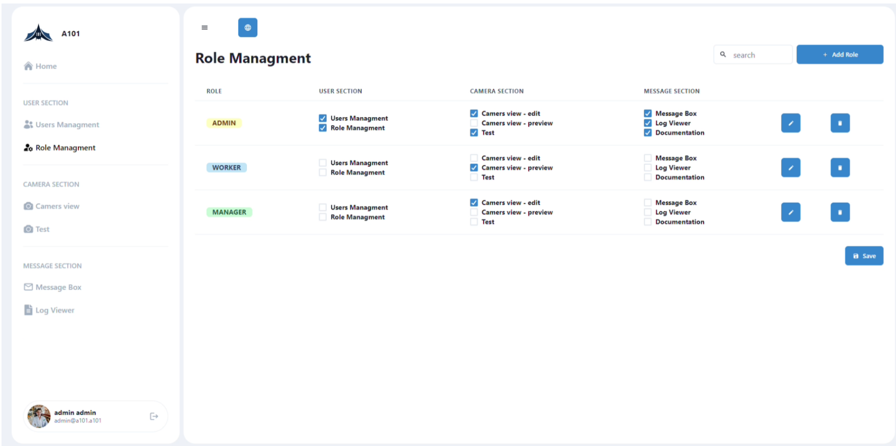


**Figure 3.8:** Role Management Page

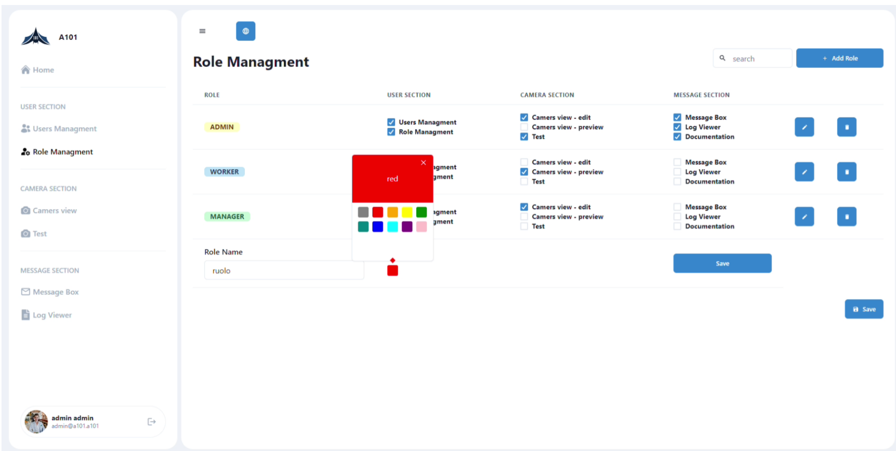


**Figure 3.9:** Role Creation

### 3.2.4 Admin - ROI Configuration Page

Another crucial feature for the Admin account is the ROI (Region of Interest) configuration page, shown in Fig. 3.10. This page is designed to provide a view of the various configurations present in the system. Each configuration is accompanied by an identifying name, a brief description of the number and type of ROIs included, and the current state of the configuration. It is important to note that multiple configurations cannot be active at the same time. For each configuration, the Admin has several essential operations available:

- **Delete:** This function allows you to remove the selected configuration from the system, keeping the list sorted and free of obsolete configurations;
- **Edit:** This allows you to update the information and details of the selected configuration, ensuring that the data is always accurate and relevant.
- **Access to the configuration page (Use):** Provides a direct link to the dedicated page to manipulate ROIs within the specific configuration, as shown in Fig. 3.11
- **Add configuration (Add configuration):** Allows adding a new configuration using a button located at the top right of the page

In the ROI manipulation page of a given configuration, the admin has access to a real-time stream of the device's camera, next to an interactive digital whiteboard. On this whiteboard, Alarm or Warning ROIs can be added using two dedicated buttons, and the ROIs can be easily manipulated via drag and drop. This allows for a visual and intuitive configuration of the ROIs. As shown in Fig. 3.12 , ROIs are displayed in real time in the video stream, and the machine learning algorithm used by the backend identifies key points of people, displaying a warning if a person enters the ROI. This helps to monitor and manage critical areas of interest in real time. ROIs should be carefully placed to ensure effective protection: for example, to protect an area, a Warning ROI should be activated first, followed by an Alarm ROI. This order avoids prohibited configurations, which would occur if an Alarm ROI is activated before a Warning ROI. The system automatically detects these prohibited configurations and displays a message suggesting to swap the ROI types to correct the error.

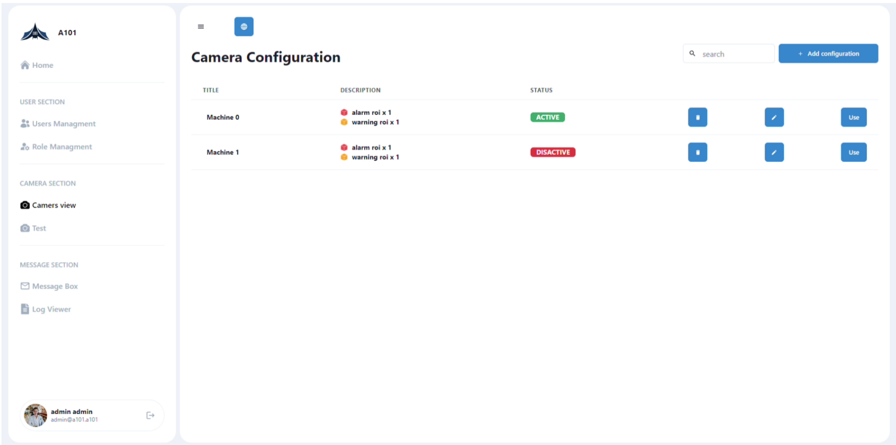


**Figure 3.10:** Configurations

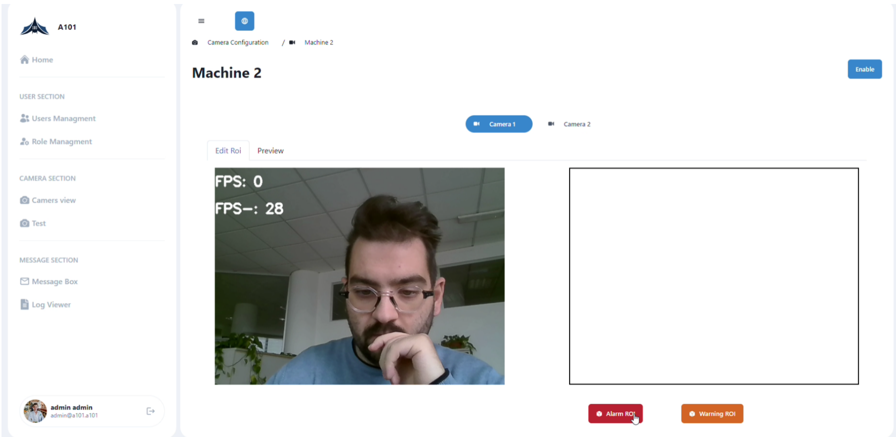


**Figure 3.11:** Configuration detail

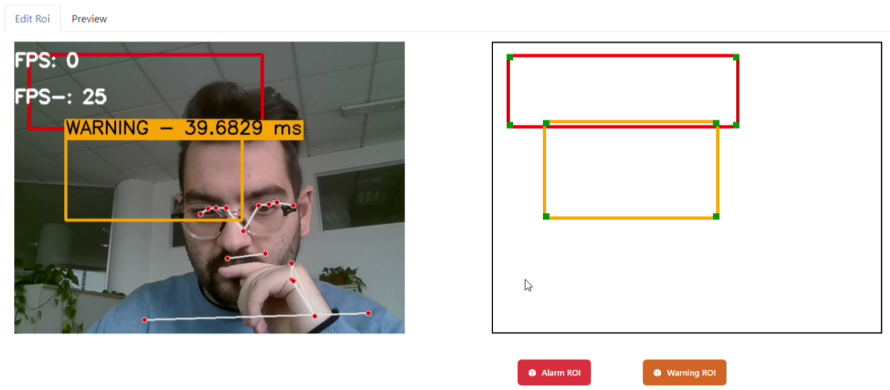


**Figure 3.12:** ROI Manipulation

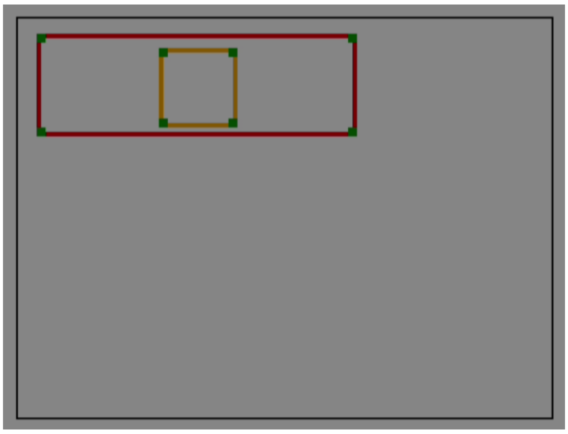

**Figure 3.13:** Configuration Forbidden

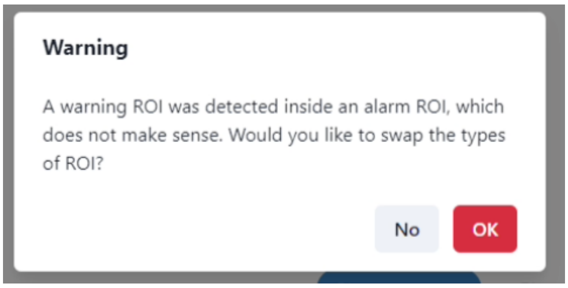


**Figure 3.14:** Error message

### 3.2.5 Admin - Log View Page

The Admin can access the log view page, a fundamental section for monitoring all the operations performed within the system. This page shows a detailed list of activities, providing crucial information such as the date, time, user, user role, action performed, the system section where the operation was performed, the outcome of the operation and an explanatory note if any. This detailed view allows the admin to have a complete and transparent overview of the actions performed, facilitating the traceability and responsibility of the operations. This is particularly useful in the case of audits or for troubleshooting, as each action is precisely documented. The Admin can examine this list through an intuitive interface that includes a search bar to quickly find specific activities. In addition, several filters are available to refine searches. These filters allow you to narrow down the results displayed based on various criteria, allowing for even more efficient management:

- **User:** Filters the operations performed by a specific user, making it easier to identify the activities of a specific operator;
- **Role:** Allows you to view the operations based on the user's role, such as Administrator or Standard User, useful for analyses based on different responsibilities;
- **Action:** Allows you to select the operations based on the type of action performed, such as modifications, deletions or other specific operations, providing a detailed view of the operational activities;
- **Section:** Filters the operations based on the section of the system in which they were performed, providing a segmented view of the activities;
- **Result:** Shows the operations based on their outcome, distinguishing between successful and failed operations, making it easier to identify any problems;

- **Date:** Allows you to view operations performed on a specific date, useful for precise time analysis;
- **Date Range:** Allows you to view operations performed within a certain time range, useful for analysis on specific periods;
- **Time Range:** Filters operations based on a specific time range, allowing you to focus on time slots of interest;

These advanced search and filtering tools greatly improve the efficiency in managing and monitoring activities, ensuring that the administrator can quickly find and analyze the information they need. In addition, the Admin has the ability to export the filtered list in Excel format, making it easy to analyze and share data with other team members or for audit purposes. This export functionality is particularly useful for creating detailed reports, keeping a record of operations and providing a solid basis for future analysis.

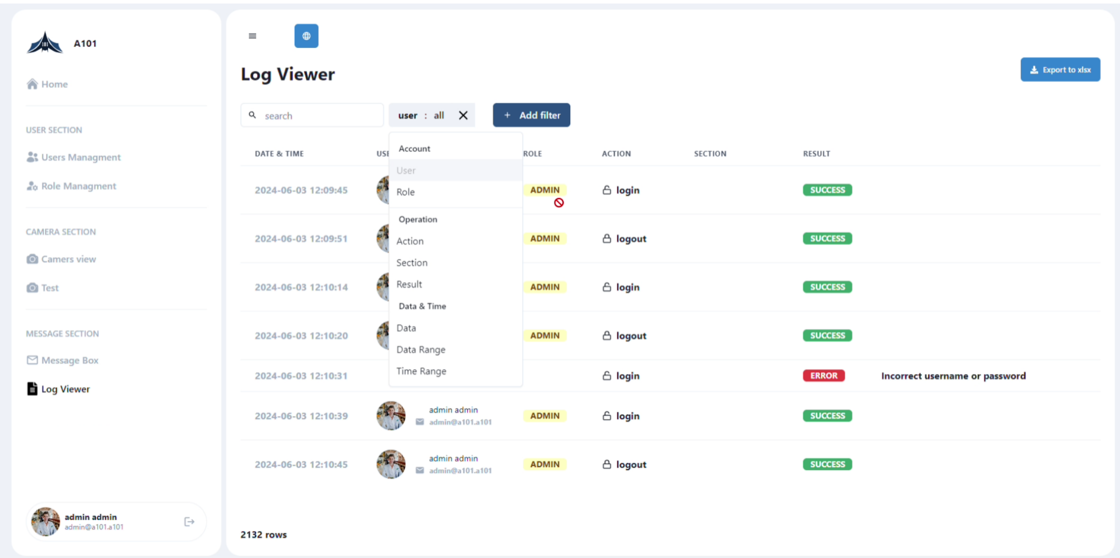


**Figure 3.15:** Log

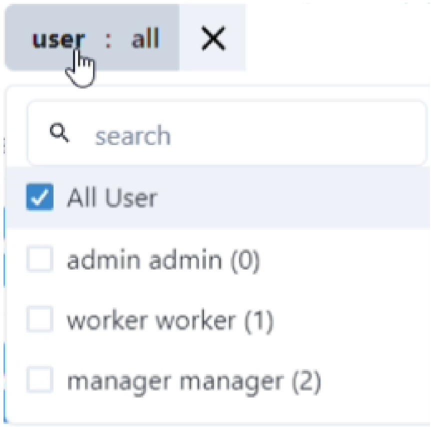


**Figure 3.16:** User Filter

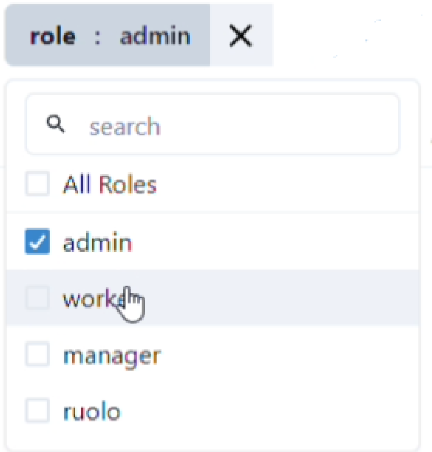


**Figure 3.17:** Role Filter

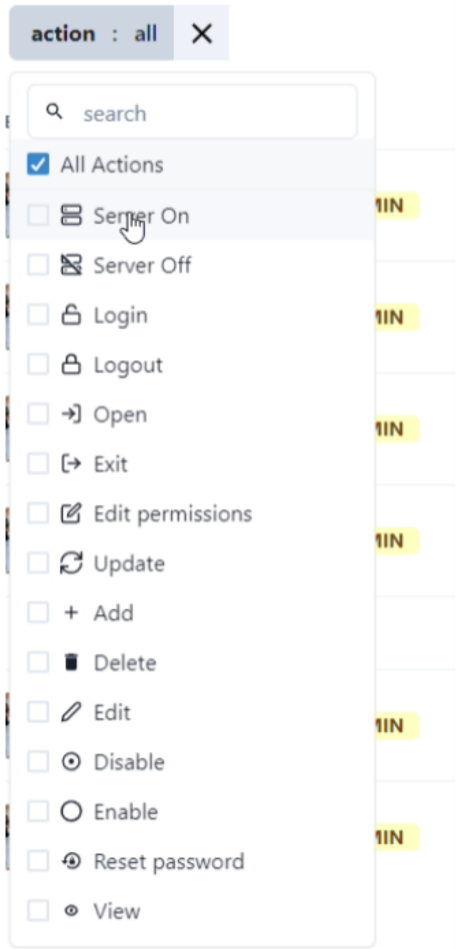


**Figure 3.18:** Action Filter

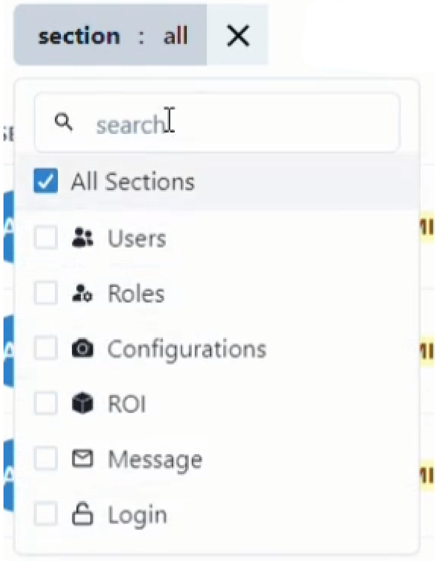


**Figure 3.19:** Section Filter

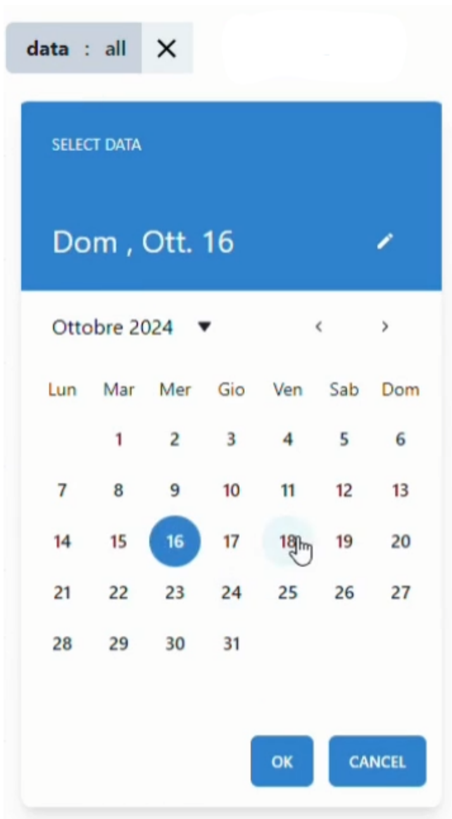


**Figure 3.20:** Data Filter

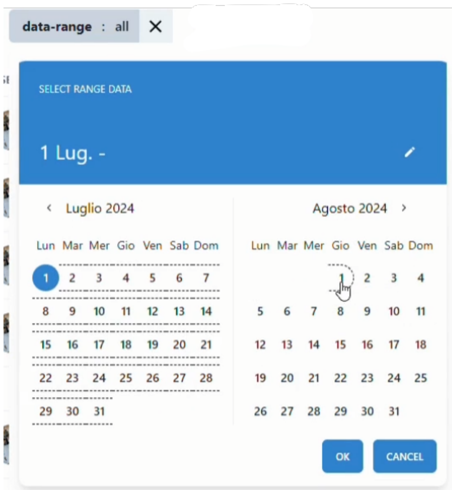


**Figure 3.21:** Data-Range Filter

# Chapter 4

# Experimental Results

In this section, the evaluation results of the developed model are presented. The evaluation was conducted using a video containing only one subject, due to the limitations of the MediaPipe library used. The evaluation involved the placement of an alert Region of Interest (ROI) in a specially selected area. Each frame of the video was analyzed and compared with the ground truth to determine the accuracy of the model.

**Figure 4.1:** Frame with ROI positioned at a dangerous point

**Figure 4.2:** Frame with subject in danger zone

#### Methodology

To evaluate the effectiveness of the model, a video was used in which a single subject was moving within a controlled environment. Due to the limitations of MediaPipe, which currently supports accurate detection of a single subject at a time, this decision was made. The video was processed to identify the presence of the subject within an alarm ROI. This area was strategically chosen to test the model's ability to correctly detect the subject and trigger the alarm.

#### Frame Analysis

A total of 520 frames of the video were analyzed. Each frame was evaluated individually to determine if the subject was within the alarm ROI. The evaluation was performed by comparing the model's predictions to the ground truth, which is the actual position of the subject manually recorded for each frame.

#### Evaluation Results

The evaluation results showed a correct prediction rate of 95%. This level of accuracy indicates that the model was able to correctly detect the presence of the subject within the alarm ROI in the majority of the analyzed frames. Some key observations are:

- **Model Accuracy:** The model demonstrated good accuracy in detecting the presence of the subject within the ROI. This is a significant result, considering the limitations imposed by the MediaPipe library;
- **Prediction Errors:** The 5% prediction errors are attributable to various factors, including variation in lighting conditions and rapid subject movements;

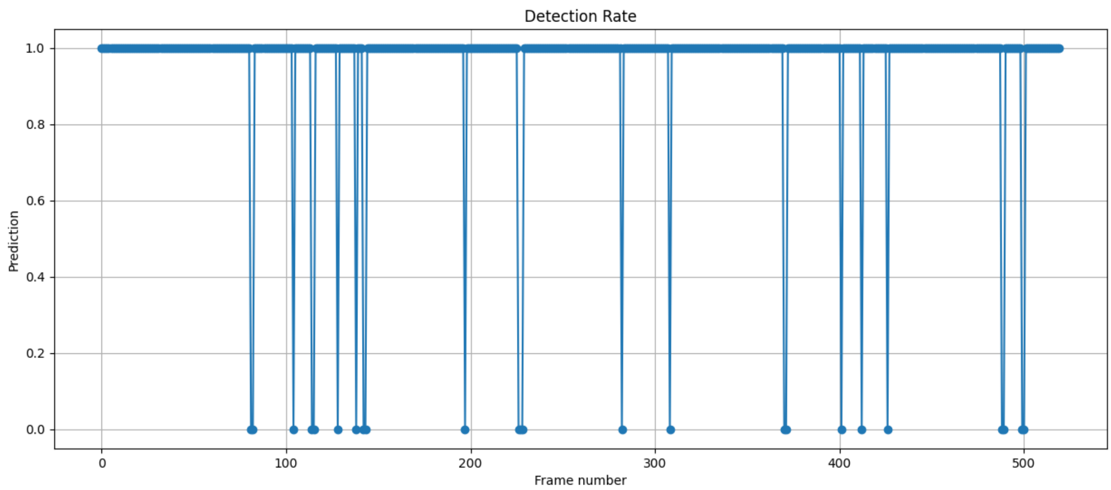


**Figure 4.3:** Graph showing the results

In conclusion, the evaluation of the model has shown that the system is able to correctly detect the presence of a subject within a ROI with an accuracy of 95%. This result is promising for the implementation of the model in industrial and security applications. However, further improvements and optimizations are needed to address the identified limitations and to ensure that the model can be used in more complex scenarios with multiple subjects and variable environmental conditions.

# Chapter 5

# Conclusions

The thesis highlighted how the A101 device, thanks to the integration of advanced technologies and artificial intelligence algorithms, can significantly contribute to the prevention of accidents at work in industrial environments. The results of the model evaluation, although conducted with the limitations imposed by the MediaPipe library, which is able to track the landmarks of only one individual at a time, showed an accuracy of 95% in detecting the presence of a subject within an alarm ROI. The A101 device, although still under development, represents a promising innovation in the field of industrial safety. The future implementation of three-dimensional ROIs, based on perspective analysis and the integration of TOF cameras, will allow to reach an even greater level of precision and effectiveness. The use of TOF cameras, in particular, will allow to obtain more accurate and real-time depth information, overcoming the limitations of perspective analysis with RGB cameras. The thesis highlights the importance of research and technological innovation for the creation of safer working environments and for the protection of workers' health. The diffusion of devices such as the A101 could contribute to a significant reduction in the number of accidents at work, promoting a culture of safety and well-being in the industrial sector. The implementation of safe access systems, as required by IEC 61496-3 §A.9.*, is essential to prevent unauthorized access and ensure the integrity of the safety system.

Further future developments include the improvement of detection algorithms through the integration of more sophisticated artificial intelligence models, such as convolutional neural networks (CNN) and recurrent neural networks (RNN). These advances will allow the system to detect and predict complex movements in three-dimensional environments with greater precision. Furthermore, it will be crucial to explore the integration of the A101 device with other existing safety systems, creating an interconnected protection network that can offer more complete and reliable coverage. The ultimate goal is to create a comprehensive and reliable safety system that can adapt to the diverse needs of industrial environments, helping to create a safer and more sustainable future of work. The long-term vision includes not only reducing workplace accidents, but also improving working conditions overall, promoting an environment where worker safety and well-being are a priority. In conclusion, the A101 device represents a significant step forward in industrial safety technology. Its ability to integrate various advanced technologies for monitoring and protecting work environments makes it an indispensable tool for companies aiming to improve safety and operational efficiency. The thesis not only explores the technical features of the device, but also highlights the importance of a proactive approach to workplace safety, highlighting how technological innovation can help significantly reduce the risk of accidents and promote a safer and more sustainable working environment.

## 5.1 Future Developments

The current system works on detecting people within 2D ROIs. However, a significant future development is the implementation of 3D ROIs, which will allow to reconstruct the person in a 3D environment. This advancement will be essential to improve the accuracy and tracking capability of the device, especially in complex environments. In the following, the challenges, partially implemented solutions and future perspectives of this development will be discussed.

### 5.1.1 3D ROI and 3D Reconstruction

The implementation of 3D ROIs requires accurate depth information. Currently, the depth coordinate (z) provided by MediaPipe is not always reliable and requires additional calculation to ensure accuracy. To overcome this limitation, in the first version of the device, which uses a simple RGB camera, the z coordinate was calculated through a perspective analysis.

#### Perspective Analysis

Perspective analysis is based on the geometric relationship between the apparent dimensions of objects and their distance from the camera lens. In particular, the distance between the right and left shoulders was used as a constant reference. At a given distance from the lens, this distance between the shoulders remains unchanged, providing a stable reference point for perspective calculations.

- **Data Collection:** Information about the distance between the shoulders and the lens was collected through a series of measurements. This data was then used to create an interpolation function that allows estimating the z-coordinate for each key point of the body.
- **Depth Calculation:** As shown in figure 5.1, thanks to this method of obtaining the depth coordinate, it was possible to map the subject in the three-dimensional environment.

This first solution allowed to create a simplified 3D representation of the person, improving the system's ability to monitor and detect movements and positions more accurately.

### 5.1.2 Implementation of 3D ROIs

A further development consists in the possibility of adding a ROI specifying the type, size, position and rotation for each spatial coordinate, in order to completely define the ROI's layout and position. This advancement allows for greater flexibility and precision in defining areas of interest and managing safety situations.

### 5.1.3 Further future developments

Despite the current progress, there are still several areas of improvement and future development to further optimize the system:

- **Integration of TOF Cameras:** Using TOF cameras would allow to obtain more accurate and real-time depth information, overcoming the limitations of perspective analysis with RGB cameras. TOF cameras measure the time it takes for light to reflect off objects and return to the sensor, providing detailed and precise depth mapping;
- **Improved Detection Algorithms:** Integrate more sophisticated AI models, such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs), to improve the system's ability to detect and predict complex motion in three-dimensional environments;

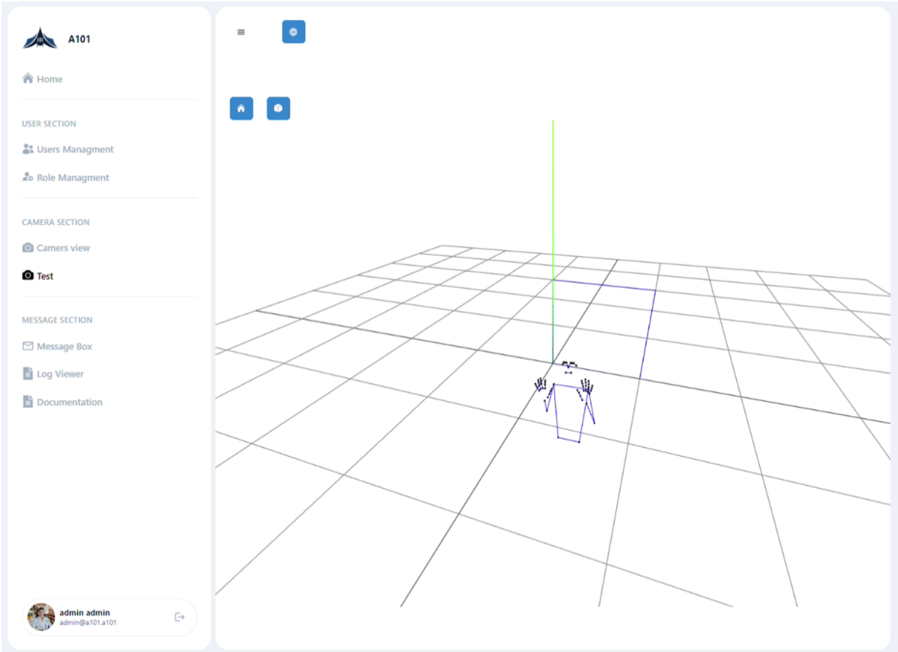


**Figure 5.1:** 3D Representation

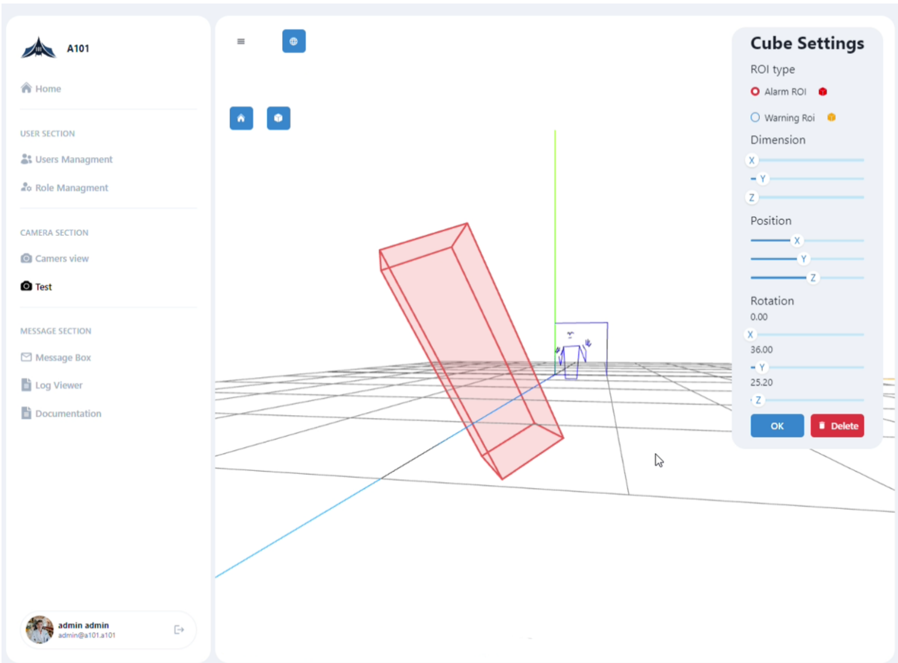


**Figure 5.2:** 3D ROI Manipulation

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