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ScienceDirect

Transportation Research Procedia 69 (2023) 344–351

Transportation Research Procedia

www.elsevier.com/locate/procedia

AIIT 3rd International Conference on Transport Infrastructure and Systems (TIS ROMA 2022), 15th-16th September 2022, Rome, Italy

Augmented reality and portable devices to increase safety in container terminals: the testing of A4S project in the port of Genoa

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Abstract

Port container terminals are intrinsically complex environments and the human factor is often the main cause of accidents. Industry 4.0 technologies enable to dispose of enormous quantity of data, process them with advanced algorithms also allowing predictivity, and provide virtual/augmented reality tools to interact with human operators. Promising solutions are spreading that use the loT paradigm to acquire data and apply Big Data techniques to manage them.

The objective of "Awareness for Safey-A4S" project, is to test a complete solution that allows field operators to be equipped with intelligent wearable devices, allowing "conscious" interaction in complex environments. This solution provides for the visualization of environment information in real time through Augmented Reality devices. These devices themselves represent a "sensor" providing information to the general system. Such information, integrated with environmental data and gathered through a specific I-IoT cloud platform and customized field devices, can improve safety and effectiveness of operations. Further support for operator safety is provided by a route tracking system aimed at directing operators, walking in the terminal, on the shortest and safest path. Such system can consider in real time the risks due to the movements of terminal equipment. The current paper presents this solution and the first field tests at PSA SECH container terminal in the Italian port of Genoa port to demonstrate the effectiveness of the proposed solution in increasing safety in complex and dangerous environments.

Keywords: safety; port terminal; augmented reality; portable devices; testing; complex environment

10.1016/j.trpro.2023.02.181

1. Introduction

People protection is a top priority. However, much remains to be done to better support operators working in complex and dangerous contexts, such as port terminals, to carry out delicate tasks such as maintenance or inspections. In most contexts, these tasks are still based on periodic visual or instrumental inspections which can lead to high costs, insufficient safety levels, poor effectiveness, and timeliness.

The environment of a container terminal, a node of the logistics and transport network where the container makes a change of transport mode (sea-road or sea-rail, or road-sea or rail-sea), is very complex due to the type of operations carried out, the goods handled and the vehicles used. Usually, it is composed of four functional areas: Quayside (sea-side operations), Hinterland (inland operations), Yard (storage operations), and interconnection areas (operations to connect the other areas).

In recent years, the issue of security has become increasingly important, and studies and applications aimed at enhancing security in port contexts are increasingly emerging. Not only "Security", but also "Safety". The first one means the protection of the terminal from criminal actions, whose main reference is the International Ship and Port Facility Security Code (ISPS Code), which in its application in port areas provides for the drafting of the Port Facility Security Plan (PFSP). The term "safety", the subject of this paper, includes everything that concerns the health of all terminal workers.

Accidents can be more easily avoided by implementing advanced technologies that actively perceive hazards and identify and enable preventive measures before accidents happen (Stiehler, 2011). Since safety can be defined as the control of a risk, it is necessary to correctly identify which situations, processes, or operations may involve a hazard and to act to mitigate it with the support of appropriate technologies. In this context, this paper aims to design and test an integrated solution based on several innovative hardware and software components in order to increase safety in complex and dangerous environments, such as port container terminals.

This paper is developed in the framework of the “Awareness for Safey-A4S” project, funded by the Italian START 4.0 Competence Center, which aims to test a complete solution that allows field operators to be equipped with intelligent wearable devices, allowing "conscious" interaction in complex environments.

1.1. Safety in container terminals

Before identifying the technologies that can support terminal operations in terms of safety, it is important to identify the most critical points. Often the human error was the main cause of accidents in container terminal, around the 53% (Budiyanto and Fernanda, 2020). There are many classifications of the main risks in a port terminal, some examples of which are given below to provide a comprehensive picture for the purpose of this paper.

Budiyanto and Fernanda (2020) analyzed the risks of a container terminal using 5 years of data from a large Indonesian container terminal (Port of Tanjung Priok (PTP), Jakarta). The types of accident that have the highest risk, obtained as a product of severity and frequency of occurrence are in order:

1. Container damage when unloading, stacking or transferring to truck trailer.
2. Truck crashes loading and unloading equipment, other trucks, operational vehicles, containers or port support facilities.
3. Workers get run over/bang down when working.
4. Loading and unloading equipment damage.
5. Dirty dock or cause environmental pollution from contents of containers

A different approach is proposed by TT club (“Top 10 risks related to container terminals,” 2019), which classifies, terminal risk categories on the basis of insurance claims. At the top of the list are accidents with handling equipment in the terminal, including quay cranes (14%), straddle carriers (10%), lift trucks (9%) and trucks and road vehicles (8%). In this context, some incidents, although frequent, might not be included as they are characterized by more limited consequences. The equipment or vehicle involved is the subject of the risk classification proposed by (PEMA et al., 2012) on the basis of 2000 insured operations over 400 ports. In contrast, the classification proposed by Sunaryo and Hamka (2017) focuses on humans and therefore on accidents that may involve them are the contact with moving equipment and the strike against something fixed or stationary. Moreover, it is important to note that the list of accidents involving staff includes exposure to, or contact with, a harmful substance, fire or explosion.

1.2. Technologies to increase safety in container terminals

Today, there are several technological applications to support container terminal safety and security. For example, in the ports of Genoa and Cagliari, the Grendi Group is using active RFID technology to increase the level of security for onshore container handlers using reach stackers. The RFID technology uses audible alarms to signal the presence of other operators within a 7-meter radius by detecting the presence of special "tags" placed on the shoulders of all terminal operators. The Port of Montreal uses Digital Twin technology to improve security within the port. With the virtual reproduction of the port area, operators can experience different types of incidents to learn how to prevent and manage them. Artificial intelligence technologies in combination with the use of drones are used in the port of Antwerp to prevent personal injury, theft and dangerous situations in general. In 2019, the Port of Barcelona experimented the V2X (Vehicle to Everything Communication Systems) communications on cranes to reduce the risk of accidents. The Tebets project -T*echnological Boost for Efficient port Terminal operations following safety-related events* used cyber-physical systems with the aim of proposing actions to effectively resolve dangerous situations (accidents, fires, natural events) by improving the decision-making process of operators in dangerous situations. The project was completed in 2021, and San Giorgio terminal of the port of Genoa was part of the partner involved in the project. The algorithms implemented were able to identify and propose less risky routes for port workers by communicating directly via SMS, Whatsapp and email. The European project SUPPORT ("Security upgrade for ports") was aimed at improving the security of European ports. During the course of the project, a number of existing port security systems were analyzed and a series of good and bad practices applied by port authorities and other stakeholders were derived. The ones presented above are some non-exhaustive best practices on the topic covered in this paper. The details of the technological solutions chosen in the A4S project are described in the next sections.

2. The architectural solution

The complete solution designed for the A4S project allows field operators to be equipped with intelligent wearable devices, allowing "conscious" interaction in complex environments. This solution provides for the visualization of environment information in real time through Augmented Reality (AR) devices. This implementation is usually more difficult than virtual reality (VR) because the effectiveness of an AR system is linked to the ability to locate it in a real space thanks to particular recognition techniques, very different from each other, which come to deeply characterize the design of the devices themselves and, consequently, also affect the development of the applications they mount. Moreover, an AR system is highly dependent on the ability to identify the objects around it and to determine where to place the information so that it can be functionally and accurately superimposed in the real world. These devices themselves represent a "sensor" providing information to the general system.

After careful analysis, the project partners selected an innovative technology based on Bluetooth 5.1 (Direction Finding) for the application of man-machine Geo Fencing as it is more reliable, scalable and relatively inexpensive compared to e.g. Bluetooth Low Energy or RFID. Two use cases of Direction Finding can be differentiated:

- Angle-of-Arrival (AoA) calculation, an Asset (to be located) is transmitting a signal and the Locators, which receive the signal, are able to determine the relative direction.
- calculation of the angle of departure (AoD), the Asset (to be located) is receiving the signal transmitted by some Beacons. The Asset is able to determine its direction relative to the Beacons.

The information from the antenna (AoA solution) and the sensor, integrated with environmental data and gathered through a specific I-IoT cloud platform and customized field devices, can improve safety and effectiveness of operations. A key aspect of an operational working environment, whether indoors or outdoors, is to monitor and record workers' exposure to hazardous chemicals to ensure their safety and health (section 1.1). Early warning systems make use of advanced algorithms (machine learning, data fusion, etc.) to analyze the raw data. In the proposed solution, the data collected by the sensors can be either made available to artificial intelligence algorithms in order to obtain various timely information on the risk in the medium and short term and allow rapid and as effective as possible interventions, or used by expert users, so as to show with graphical representations the variation of the parameters, leaving the interpretation and identification of potentially dangerous situations to the expert process managers.

The system architecture designed within the A4S project, with the aim of enhancing safety in complex contexts, is provided in Figure 1. The architecture is composed of the following components:

1. *HoloLens 2*: an augmented reality viewer. It is a wearable device that allows the user to have his hands free and move in greater safety. It was developed by Cetena Spa company.
2. *WeTAG:* a device wearable around the neck using an eyelet, carabiner or belt clip, rechargeable via USB C such as mobile phones. It was developed by Smart Track Srl company;
3. *Bluetooth Low Energy Anchor Angle of Arrival (AoA):* a device to be mounted on a wall or on a pedestal capable of calculating the angles of arrival and the distances of the radio signals coming from WeTAG by means of an array of antennas; developed by Smart Track Srl company;
4. *environmental sensors: sensors to detect temperature and gas, developed by FOS Spa company;*
5. *safe router:* a dynamic algorithm which provides the best and safest route to choose, developed by IROI Srl company;
6. IoT Hub: a platform - developed by FOS spa company - capable of collecting information from heterogeneous sources, pre-processing, validating and evaluating the information, storing it in a database and communicating with the various project subsystems both to provide data to the processing modules and to exchange information with users;
7. *Geofencing tablet:* a tablet mounted on the equipment in order to visualize the interactions between the handling mean (i.e. reach stacker) and the ground operator.

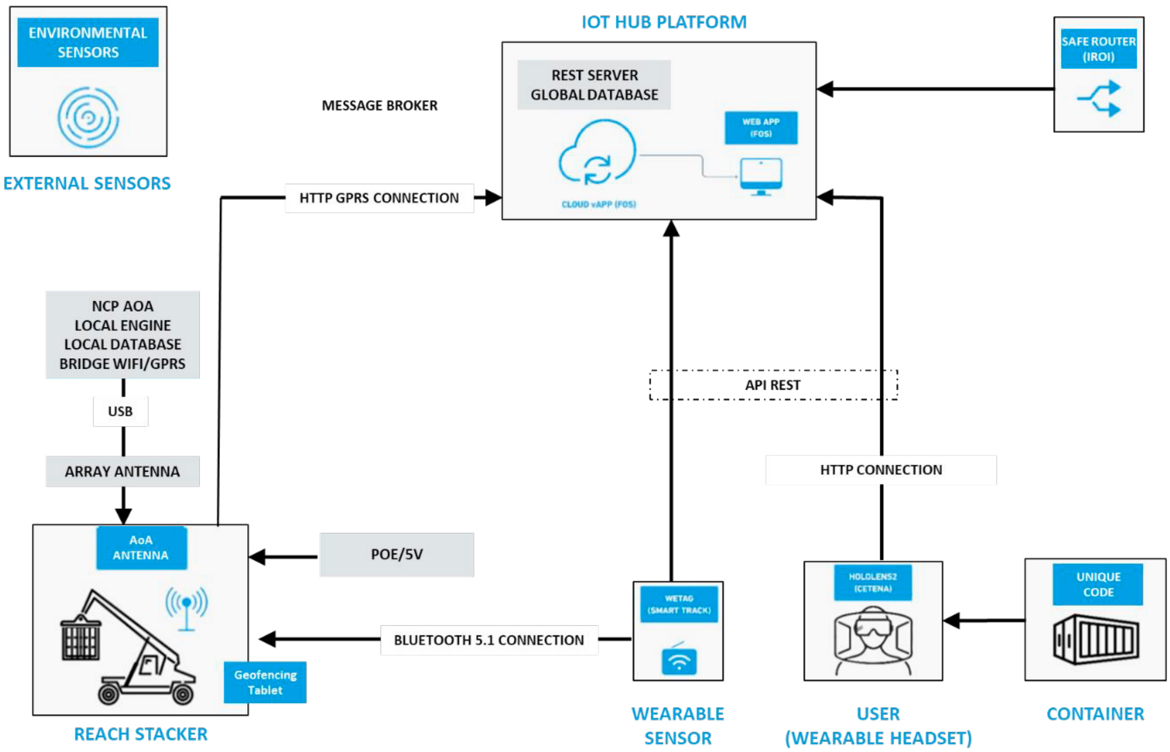


Fig.1. System architecture

As shown by Figure 1, both subsystems (HoloLens 2 and Anchor AoA) communicate with the cloud server via HTTP protocol; the communication carrier used is 3G/4G connectivity. In particular, the AoA anchor communicates the status of the WeTAG to the server through event REST GET APIs, while the HoloLens 2 device polls the server again through the REST GET API.

3. Experimentation of the proposed solution

Container terminals are intrinsically complex environment: heavy suspended loads are handled by large dangerous equipment in relatively small areas, with human operators moving around. For this reason, they are an ideal application environment to test the A4S innovative solution. Such solution was tested at PSA SECH container terminal, also known as "Terminal Containers Porto di Genova S.p.A.", which is operative in the port of Genoa since 1993. With approximately 303.213 TEUs operated in 2021 and a maximum annual capacity of 550,000 TEU, PSA SECH container terminal ranks among the main import/export terminals throughout Italy. In an area of 205,000 square meters, the terminal handles 5 superpost-panamax SSGCs quay cranes, 6 RTGs (+ 2 for rail facility) cranes, 6 RMGs cranes, 17 reach-stackers, 8 forklifts and 25 yard tractors.

The proposed solution regards two main operational scenarios: 1) Smart Reach Stacker, and 2) Dangerous Goods Identification.

3.1. Scenario 1: Smart Reach Stacker

This operational scenario allows to avoid man - vehicle collision and to send safety signals. Thanks to the wearable support connected to antennas and sensors, the reach stacker operator - who is handling the containers - receives information in real time on the presence of operators working on the ground and on any obstacles in the restricted area limited for maneuvering. The operator, by wearing the HoloLens 2 equipped with the WeTAG device (Fig. 2a), can receive localized alerts and alarms of obstacles and/or other emergencies, such as a "man down" alarm.

An antenna in Bluetooth Low Energy AoA technology is installed on the roof of the reach stacker (Fig. 2b), containing a small server for data processing and powered by the battery of the reach stacker itself. Each operator is equipped with a WeTAG wearable device. These devices exchange radio frequency information with the antenna mounted on the reach stacker. The server inside the antenna calculates the arrival angle of the signal and estimates the communication distance by analysing some parameters. The geofencing tablet on the reach stacker is equipped with a simple interface in which two safety "bubbles" are usually configured for pre-alarm and alarm (when the operator is very close to the vehicle and therefore in a potentially dangerous situation). Pre-alarms and alarms can also be conveyed on the Hololens 2 display (Fig. 2c) and represented with a yellow/red traffic light and a directional arrow (if in front, behind, or on the side of the reach stacker). For privacy purposes, there is no worker localization: communication is exclusively between the reach stacker and the operator within a range of a few tens of meters, within the created safety bubbles. It is also possible to use the WeTAG portable device to detect the eventual fall of a ground operator (man-down verification). Voluntary alarms can be enabled using the appropriate SOS button, enabling the GPS only following an emergency event, with the possibility of geo-locating where the alarm occurred.

The data platform collects information from the environment by integrating specific IoT sensors and existing data sources, and merges the data with those coming from the devices on the person, to obtain a complete view of the present situation and the historical trend. With data analysis, some mathematical methods were applied to recognize the presence of risk situations in the environment in which the operator moves. These methods carry out the matching between patterns and/or predefined rules and information of various kinds from the environment in order to quantify the risk present on parts of the paths.

a *b* *c*

Fig.2 - HoloLens equipped with WeTAG (a); reach stacker mounted with AoA antenna (b); Hololens 2 viewer near the reach stacker (c)

A graph model of the possible routes was defined, associating both a measure of time/distance (T/D) to the various sections of the paths, corresponding to the arcs of the graph, and a measure of the risk associated with crossing them. The graph is used to define a set of optimal paths between a starting point and an ending point. An optimal bi-objective algorithm was developed to consider both the T/D and the risk factor to follow it. The algorithm is dynamic as it can be run starting from the current position of the person and whenever new data is available, in order to avoid new risks or take advantage of situations of ceased danger. The main benefits of scenario 1 are represented by: (i) predictivity and decision-making speed; (ii) decrease in accidents, and (iii) speed of moving in safety.

3.2. *Scenario 2: Dangerous Goods Identification*

This scenario relates to the identification of hazards goods and its management. The purpose of this use case is to allow the terminal operator to quickly identify the dangerousness of the goods and to directly access the information relating to the container through the use of augmented reality, through the HoloLens 2 device. In this scenario the ground operator moves in the container storage area and, thanks to the wearable support, by framing the international classified label positioned on the sides of the container, receives real-time information relating to the hazard class of the load/container and the rules to be respected in terms of location and safety with respect to other loads. The user is guided and supported by the system in the correct storage and security check of the site.

The operator also has the possibility to verify the correct positioning of the goods and, in the presence of errors, to communicate the correct position to the internal database.

Also, in this scenario, with the aid of special sensors connected to the device, the operator has the possibility to receive localized warnings and alarms of obstacles and/or other emergencies, such as "man down". The main advantages of this use case are: (i) predictivity and speed of verification; (ii) accident prevention and (iii) preparation of operators (training during activities).

3.3. Testing at PSA-SECH container terminal in the port of Genoa

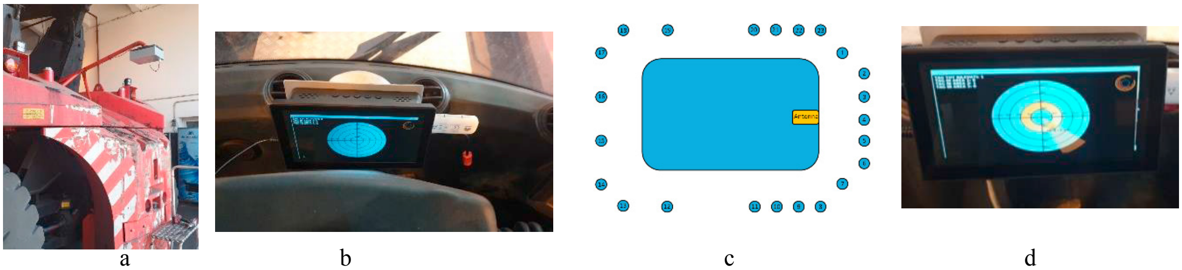
The proposed solution was tested in the outdoor environment of PSA SECH container terminal in the port of Genoa, with the aim of validating in the field the integration between the hardware and software objects developed by the project partners. The purpose was the system testing, so a limited number of elements were involved to better monitor the outputs. The testing lasted one day and involved 1 operator, 1 reach stacker, and 5 containers.

The system integration was evaluated by checking the reception of the data according to the following flows:

- localization events sent by WeTAG to the IoT HUB;
- geo fence events sent from the monitor via USB-GPRS dongle (at event);
- geo fence polling requested by HoloLens 2 to the IoT Hub platform (every 3 seconds);
- optimal path events requested by the IoT Hub towards the SafeRouter (every 3 seconds).

To verify the points listed above, the following validation setup was performed:

a) install the AoA antenna on the reach stacker at a height of at least 2.5m (Fig. 3a);
b) install the geofencing tablet on the reach stacker (Fig.3b);
c) track the operator (every 4 minutes) to record the location events generated by Smart Track on the IoT Hub (Fig. 3c);
d) trace the operator around the reach stacker by using the geofencing tablet installed on the reach stacker (every 4 minutes). Location events generated by Smart Track are recorded on the IoT Hub (Fig. 3d);
e) approach and removal of the person equipped with WeTAG from the reach stacker to verify the precision and accuracy of the measurement and record the Geo Fencing events on the IoT Hub;
f) generate the optimal path by relying on the Safe Router algorithm on the basis of the data exchanged between the IoT Hub platform and Safe Router.



a b c d

Fig. 3. AoA antenna installation on the reach stacker (a); geofencing tablet installation on the reach stacker (b); operator tracking (c); operator tracking by the geofencing tablet (d)

The localization of the operator and the reach stacker takes place through the on-board connectivity to the WeTAG device. The location of the terminal operator and the reach stacker, which takes place every 4 minutes, is necessary to calculate the optimal route that the reach stacker driver must travel to move from the current position to the one defined as the destination. This is done by the SafeRouter module, which communicates on the one hand with a Server system responsible for running the algorithm for dynamic path optimization and, on the other, with the Client on the operator's mobile device. The Server processes the optimal path in real time to guide the operator from its point of origin to its destination in the shortest possible time, while ensuring the operator's safety by taking into account the movements of the various vehicles present in the PSA SECH Terminal. These vehicles, in fact, through IoT communicate their current position and speed with a sufficient frequency; similarly, the operator's mobile device provide the Server with the position and speed. The acquired position is communicated to the IoT Hub by means of GPRS connectivity.

Some outdoor tracking tests were carried out in the area in front of the PSA-Tech maintenance warehouse with the aim of collecting enough data to calculate the optimal route. Fig. 4 shows a screenshot of the IoT Hub platform with the optimal path calculated by the IROI platform from a generic location point of the reach stacker to the predetermined destination.

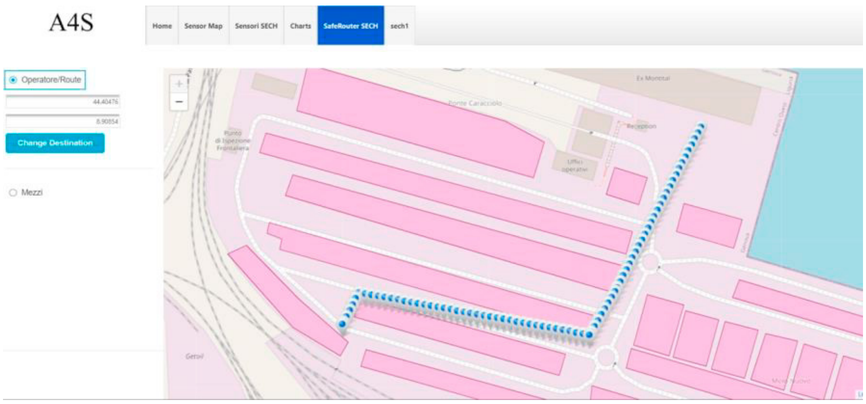
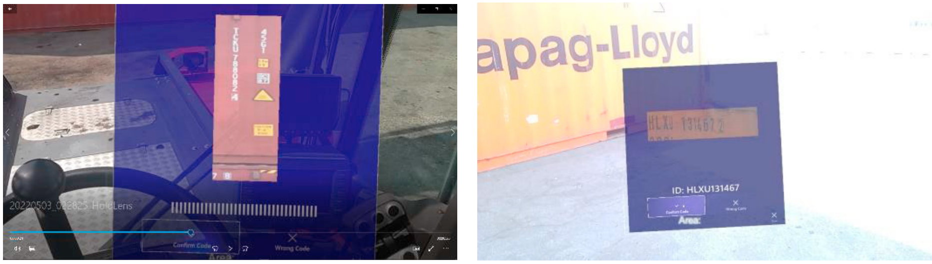


Fig. 4. Screenshot of the IoT HUB platform with the optimal path calculated by the IROI platform- an example

The proper functioning of the Hololens 2 viewer (Fig. 5a) was also evaluated. In particular, its ability to read container codes in different operational situations was tested:

- under different light conditions: the reproduction of holograms in a very bright environment makes the display less clear but still sustainable considering the easily recognizable reference indicators;
- different heights of the container codes to be read: starting from the bottom, codes from the first to the third row are legible. From the third row onwards, both for a speech of light glare and for reading distance, the readability loses sharpness and despite the accuracy of the photo taken, one could incur in a non-OCR reading of the code itself;

- both horizontal and vertical codes. For this reason, before taking the shot, the grid mode was implemented in which the operator can select the orientation and then have the trace of the bounding box in which to circumscribe the code during the shot.



a ***b***

Fig. 5. Hololens 2 viewer framing the container code - two examples

Once the image is captured, the Hololens 2 application makes a cutout on the viewer. The cropped image is then sent to the IoT Hub platform, which processes it and outputs the OCR reading that corresponds to the scanned code.

The Hololens has been shown to work correctly in the following conditions: good visibility (especially outdoors), not excessive lighting, distance of about 2 meters from the container, frontal positioning of the user with respect to the container, correct framing of the code, firm snap, and use of the wearable possibly charged.

4. Conclusions

This paper presents an innovative technological solution that makes it possible to recognize and locate the risks for workers operating in complex dangerous environments, such as port areas, with the aim of increasing their safety. The novel application relies on both hardware and software components, i.e., augmented reality, portable devices and a dynamic routing algorithm. The proposed solution can represent an effective decision support system, capable of suggesting in real time to the worker the best way to move in the workplace in safe conditions while performing his/her activities.

The solution was tested in a real container terminal located in the port of Genoa and the testing results demonstrated that it is well functioning. The test results are closely related to the operation of the integrated solution and not to the measurement of safety indicators.

Further research will be devoted to further testing the solution over a long period of time and a larger area in order to quantify the safety increase through the use of suitable KPIs. In addition, it will be tested in other container terminals on different equipment such as rail-mounted gantry cranes or trailers.

Acknowledgements

This work was supported by the project "A4S-Awareness for Safety", 3rd place of a competitive call funded by START 4.0-Security and optimization of strategic infrastructures 4.0" Competency Center.

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