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Training on LSA lifeboat operation using Mixed Reality

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Abstract: Background This work aims to provide an overview of the Mixed Reality (MR) technology's use in maritime industry for training purposes. Current training procedures cover a broad range of procedural operations for Life-Saving Appliances (LSA) lifeboats; however, several gaps and limitations have been identified related to the practical training that can be addressed through the use of MR. Augmented, Virtual and Mixed Reality applications are already used in various fields in maritime industry, but their full potential have not been yet exploited. SafePASS project aims to exploit MR advantages in the maritime training by introducing a relevant application focusing on use and maintenance of LSA lifeboats. **Methods** An MR Training application is proposed supporting the training of crew members in equipment usage and operation, as well as in maintenance activities and procedures. The application consists of the training tool that trains crew members on handling lifeboats, the training evaluation tool that allows trainers to assess the performance of trainees, and the maintenance tool that supports crew members to perform maintenance activities and procedures on lifeboats. For each tool, an indicative session and scenario workflow are implemented, along with the main supported interactions of the trainee with the equipment. **Results** The application has been tested and validated both in lab environment and using a real LSA lifeboat, resulting to improved experience for the users that provided feedback and recommendations for further development. The application has also been demonstrated onboard a cruise ship, showcasing the supported functionalities to relevant stakeholders that recognized the added value of the application and suggested potential future exploitation areas. **Conclusions** The MR Training application has been evaluated as very promising in providing a user-friendly training environment that can support crew members in LSA lifeboat operation and maintenance, while it is still subject to improvement and further expansion.

Keywords: Augmented Reality; Mixed Reality; Maritime training; Cruise industry; Lifeboat operation; Lifeboat maintenance; H2020 research project

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1 Introduction

The International Maritime Organization (IMO) has identified the human element as one of the key attributes for the safety of life at sea and a contributing factor to most of the casualties in the shipping sector[1]. The International Convention for the Safety of Life at Sea (SOLAS) is an international maritime treaty which requires signatory flag states to ensure that ships flagged by them comply with minimum safety standards in construction, equipment and operation. As part of the SOLAS code, there is the requirement that all personnel on vessels at sea must undertake Standards of Training, Certification and Watchkeeping training (STCW)[1]. Emergency drills and training have the objective of preparing a trained and organized response to emergencies, which may have critical impact on passenger and crew safety and unexpectedly threaten loss of life at sea. Based on the role of each member onboard, the training prepares personnel for safe and effective use of LSAs, starting with basic use of Personal Survival Equipment and ranging up to the management of whole vessel LSA systems.

Currently, training is conducted either onboard the vessel or at qualified training centers. IMO has developed a series of model courses which provide suggested detailed teaching syllabus and learning objectives to assist instructors develop training programs to meet the STCW Convention standards for seafarers. The courses that are conducted at training centers cover a generic range of different LSA equipment, while training onboard is focused on the specific equipment that is installed in each particular vessel. Training courses usually consist of a theoretical part, where the training material is presented along with some basic demonstrations, as well as a practical part, where participants familiarize themselves with the equipment. The training material covers all common types of ship-board safety equipment and procedures, such as emergency plans, survival crafts and techniques, personal protective equipment, search and rescue operations, etc. The practical part provides a hands-on training on the deployment of the equipment, such as launching of LSA, use of Marine Evacuation Systems etc.

However, the quality and efficiency of such training courses are subject to improvement. One of the issues highlighted by the training conductors is the frequency of dedicated drills, where crew members can practice the physical deployment of LSAs. Currently, crew members participate in a physical deployment of LSAs every two or three years, which makes their practical training less memorable. Moreover, physical deployment of LSAs comes with the risk of human error that may lead to physical injuries and equipment damages. All the above indicate that the main source of training remains the theoretical part through video presentations and equipment operational manuals. This type of training has been recognized as less interactive, less engaging and as a result less efficient. This is one of the issues that the EU-funded SafePASS project (Grant agreement ID: 815146) aims to address. SafePASS aims to redefine related evacuation processes, systems and equipment as well as the international regulations for passenger ships. As part of the SafePASS toolkit, a dedicated MR training application has been developed which targets to support the acquisition of procedural skills to enhance the situational awareness of cruise ship personnel for LSA lifeboat operations[2].

2 Related work

2.1 AR/MR in safety training

Several cutting-edge technologies have been adopted by the industry in the last years, in order to support some of the provided services, improve the human experience and the effectiveness of procedural training. Among these technologies, AR, MR and VR have been identified as very promising technologies with great advantages, such as enhanced visual training, safe training environment, enhanced trainee engagement, better retention levels and powerful analytics. The main characteristics and differences of the above technologies can be identified in the following definitions. Virtual Reality is the computer-generated simulation of a threedimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors. Augmented Reality is an interactive experience of a real world environment where the objects that reside in the real world are enhanced by computer-generated perceptual information, sometimes across multiple sensory modalities. Mixed Reality is also a view of the real world that allows physical and virtual objects, such as digital twins, to co-exist in mixed reality environments and interact in real time. Along with the technological advancement and capabilities of Head-mounted displays (HMDs) such as MS HoloLens 2[①], Mixed Reality provides the means for creation of close-to-real environments for training applications overriding any difficulties and hazards that exist for on-spot training programs. AR/MR technology has been adopted by various sectors as the tool to develop contemporary and efficient training tools. Such examples are the Construction sector, the Occupational Health and Safety[3], the Manufacturing sector[4], the Medical sector[5] and Vocational Training[6].

2.2 AR/MR in maritime sector

In Maritime Sector, AR/MR use cases may deal with Sales and Marketing, where relevant projects often serve as a “door opener” to introduce Virtual or Augmented Reality in a company, support the sales process and open a window to the “future” of next generation LSAs. Other use cases of AR/MR technology in maritime sector can apply to Product validation, Harbor Surveillance, Design and Production[7]. Moreover, ship operation can be benefitted by AR through relevant use case for ship bridges, improving situational awareness and thus enhancing maritime safety[8]. In addition, VR has been applied extensively for ship simulation platforms[9], ship bridge simulation[10] and Ship Handling Simulations[11]. Additionally, another important domain where AR/MR technology can significantly contribute is the marine navigation. Through the creation of a novel interface and the superimposition of virtual images on the outside world, AR/MR can support the operator, enhance collision avoidance and speed up effective information processing[12]. In this way, the use of AR/MR can reduce the cognitive ergonomic load of human operators, increase safety and improve life on board by simplifying navigation and monitoring of the marine environment[13]. Furthermore, AR/MR can be exploited for remote ship inspections, since it enables the inspector to conduct an augmented survey, through drones' or robots' video stream feed using AR features, avoiding on-site visits and minimizing associated costs. In parallel, the risk of human presence in critical environments and processes is reduced, the on-site survey costs are minimized and the overall performance of asset maintenance is improved[14].

2.3 AR/MR in cruise industry

With regards to the cruise industry, the use of Augmented, Virtual or mixed reality has been introduced in the recent years, with relevant applications being available either prior to a cruise or even onboard, in order to provide interactive content about the provided services. The pre-cruise applications are mainly used by potential customers that are interested to take a virtual tour and have a clearer view of the available vessels, destinations and services onboard[15]. Additionally, AR was identified as a strong alternative for promoting tourist attractions and destinations, overcoming the challenges stemming from the COVID-19 pandemic and the associated restrictions set worldwide[16]. While onboard, cruise lines offer AR-based applications that are used for gaming and entertainment purposes, or even for fully interactive and thematic cruise ships, such as “Disney Uncharted Adventure”. Another typical category where the AR technology serves as enabler is the promotion of organized shore excursions during a cruise. It can also be exploited by travel agencies to showcase future customers the sites of interest that can be visited during the cruise[17].

However, the use of AR/MR applications onboard cruise ships is limited to areas related to entertainment in

[①]https://www.microsoft.com/en-us/hololens general, such as gaming, promotion of products/services etc., aiming to provide a virtual but also “hands-on” experience of the provided service. Subsequently, the targeted audience for such applications is mainly the passengers, since they are the main customers of all entertainment services. This leaves aside the activities performed by crew members related to the operation of vessel equipment that are performed using conventional methods and procedures. In the last years, AR/MR experience has been widely used in training industry, with a significant impact on the human experience. Given the potential of such technologies and the need to improve current practices and procedures related to training and maintenance of LSA, it is easily concluded that AR/MR can significantly contribute to the enhancement of crew awareness, increase their interaction with vessel equipment and support crucial operations related to the use of LSA.

3 Methods

3.1 Methodology for user requirements' elicitation and system specifications' definition

Following the analysis above, there is an important potential for MR development and exploitation in maritime sector and especially for training purposes. As part of SafePASS project, the MR Training Application was developed to support the training of crew members in equipment usage and operation, as well as in maintenance activities and procedures. In order to develop an MR tool that would address actual user needs and would cover current gaps in maritime industry, a detailed methodology was followed covering the whole design, development and validation process. This methodology consisted of 6 major steps: (1) collection of user requirements; (2) system specifications and design; (3) definition of use cases; (4) application mock-ups; (5) prototype development; (6) validation and evaluation.

The elicitation of relevant user requirements was based on principles of both the Design Thinking Process, as well as of the Goals Based Requirements Approach, while the feedback of two major players in LSA industry was collected (SURVITEC & VIKING). Following this approach, a general need was extracted for use of MR applications to facilitate ship evacuation for both passengers and crew. Additionally, other user requirements were related to the improvement of crew safety training efficiency by incorporating different training scenario and enhanced visualization and interaction (digital twins, AR features), as well as the increase of crew confidence in equipment use and in particular LSA equipment by being able to actually interact with the equipment for training purposes, and use alternative training methods such as MR/VR training.

These user requirements were further analysed and translated into functional and non-functional requirements, as well as system specifications that served as the basis for the development of the MR Training application. Two distinct use cases were defined with corresponding workflows, one related to the equipment use training and evaluation and the other related to the equipment maintenance training. Each use case was composed by a sequence of steps that need to be followed by the user, in order to successfully complete the training or maintenance workflow scenarios. The application was also developed to support the evaluation of trainees' performance. Based on these use cases, the application mock-ups were developed and assessed by industry players that provided valuable feedback about real implementation of the application, leading to the release of the application prototypes. These prototypes were validated in both lab and real environment, involving also targeted user groups that tested and evaluated the application. The evaluation was based on observing the time required for the completion of the testing scenarios and on the analysis of questionnaires about the motivation and user experience by the user groups. More details about the functionalities provided by the application are presented in the following section.

3.2 MR training application

SafePASS is introducing a tailored MR application for training for large passenger ships, based on the requirements elicitation process. The MR application that has been designed and implemented is a set of tools aiming to assist and enhance already existing training procedures and to facilitate the generation of new training scenarios and environments in the future for both crew members and LSA manufacturers. The developed MR application consists of three different tools, according to the feedback received by LSA manufacturers with the regards to LSA equipment and evacuation processes. The MR Training tool enables crew members to follow and learn step by step how to deploy the LSA during an emergency evacuation event. The MR Training Evaluation tool enables trainers to test crew members and overview their performance on an LSA procedure based on knowledge from previous training sessions. The MR Maintenance tool enables the overview of procedures provided by LSA manufacturers regarding the required maintenance of the on-board LSA equipment.

3.3 Equipment and technologies

The application is developed in Unity[②], a powerful 3D/2D game engine for creating interactive, real-time content, VR, AR and MR multi-platform applications. Mixed Reality Toolkit 2 for Unity is an open-source, cross-platform development kit for mixed reality applications which intends to speed up application development for Microsoft HoloLens. Azure Spatial Anchors provide a durable representation of a 3D point and orientation in a space, being persistent and shareable among application sessions and different devices. The equipment used for the implementation and testing of the application are a HoloLens 2 head-mounted mixed reality device, a COLLADA 3D model (COLLADA is an interchange file format for interactive 3D applications) of a Minima 88 lifeboat and an actual Minima 88 lifeboat used for training purposes.

3.4 MR training tool

The SafePASS MR Training Tool is a component of the application which uses Mixed Reality to attach an LSA digital twin on real environment allowing real time interaction with its parts and targets to assist crew members and LSA manufacturers to train on handling LSA lifeboats, through various scenarios provided. The training is accomplished exploiting the real time interaction with the virtual LSA (digital twin), detecting user's performed actions and requesting the user to successfully accomplish each step of the training scenario. For each step, useful information is provided through images, text, videos and animations on the corresponding virtual parts of the LSA (Figure 1).

Each scenario is described in a JSON file that provides the number, the order of the steps, title and model to be loaded. For each step the information described in the file the accompanied media files, the type of interaction, the part of the model to be interacted with, interactions restrictions, other attached parts to the active action and general info such as title, description and tooltip content. This method of configuration was selected in order to be able to generate dynamic virtual environments giving the flexibility of generating multiple scenarios, ease of minor justifications along with ease of content alteration. The first step of the Training Tool is to allow the trainer to establish the training area. Upon a

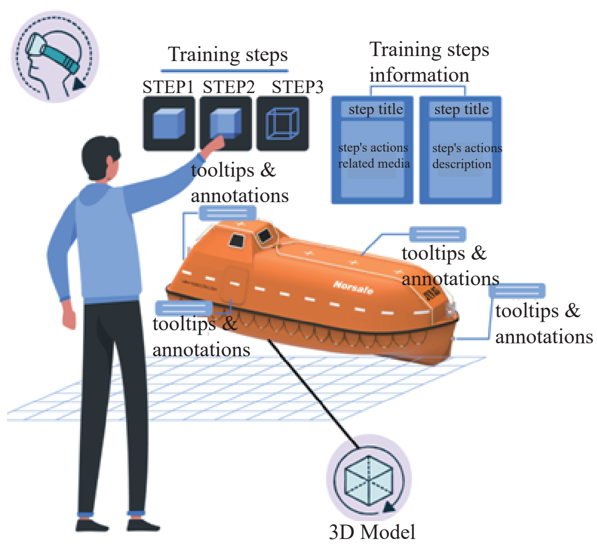

Figure 1 Training tool mockup[18].

[②]https://w.ty.com/

scenario is selected the user is requested to scan the area around to load the model attached to the floor. The model is loaded to a close to real size. The trainer can adjust the size of the model and the position on X axis to fit the available room and training purposes (Figure 2). At this point, the trainer may create a Spatial Anchor to be shared via visual recognition. This procedure allows the trainer to define a repeating training environment throughout different application sessions.

Figure 2 Positioning, scaling and anchoring 3D model.

Once a scenario step is loaded, the application generates the accompanying information panels (Figure 3). A list of the available steps is generated, as well as a panel with images and textual information, a video player, a directional indicator to the part to be interacted, a tooltip on that part and an animation giving visual information for the expected interaction. The user can handle all these panels through a hand activation menu.

Figure 3 Information and video panels.

In order to complete the active step, the user must interact with the active object (Figure 4). Two general modes of interactions are supported by the application. “Simple” mode indicates that the user has just to tap the enabled part to actrate it. “Complex” mode indicates that the user has to perform the exact action described in step data. The implemented actions are “press”, used for buttons or other pressable parts, “move”, user can move the active part to the designated direction, “rotate”, user can rotate the part on the designated axis for a specified number of degrees, “screw”, “unscrew”, the user has to rotate and move the item along the designated axis performing certain loops. Furthermore, all the above actions can be performed by parts of the digital twin that are described as attachments of the active step in the scenario file. The attached actions can be performer “after” or “parallel” to the active action. The purpose of the complex actions is to enable the muscle memory when repeatedly performing training procedures.

3.5 MR training evaluation tool

The Training Evaluation tool is a tool specifically requested by LSA safety trainers. Similarly with the MR training tool it uses Mixed Reality to attach an LSA digital twin on real environment and exploits real time interaction with its parts to detect user's performed actions. Its purpose is not only to address the need of trainers to test and evaluate the performance of trainees on specific emergency procedures but also to evaluate the effectiveness of training courses and sessions. The developed tool can also be described as the “Free Interaction Tool”. Upon the start of an evaluation session, the trainee is given only the goal of the scenario to be completed. The virtual environment setup follows the general built of the training tool. A JSON file contains the information of the model that will be used, the interactable parts of the model, even if they are not required actions for the fulfillment of the final goal, the allowed actions on interactable parts. Each action contains a range in its interaction so as not to guide the trainee to the correct final state of the selected part. For example, a switch that contains the “rotate” action may be rotated (–90, 90, 180) degrees. The challenge for the development of the tool is tracking of the order and the correctness of performed steps. In order to achieve this a set of rules are attached to each required step describing the actions that must be performed beforehand and the state of their corresponding parts. All rules contained in each step must be fulfilled for the performed action to be marked as valid. In case an action fails the validation, a direct message is given to the trainee including a general description of steps that have to be previously performed, giving the trainer the option to either continue or end the evaluation procedure (Figure 5). Once an evaluation has been concluded various useful statistics are provided such as time elapsed and number of errors.

3.6 MR maintenance tool

The SafePASS MR Maintenance Tool is a Mixed Reality application that targets to assist crew members and LSA manufacturers to train on handling maintenance procedures performed on LSA lifeboats. The maintenance scenario is accomplished on actual lifeboats carried on a cruise ship or located at training facilities, such as the Viking Safety Academy training facilities in Lavrio (Greece). For each maintenance scenario step to be performed, useful information is provided through images, text and videos on the corresponding parts of the LSA. Additionally, animations of virtual parts are provided on the actual equipment if a matching 3D model either of the whole LSA or of the active part is provided (Figure 6).

The concept of the maintenance scenario creation is similar to the one followed by the Training Tool. Each scenario is described in a JSON file that provides the number, the order of the steps, title and the model if any to be loaded. For each step the information described in the file contains the accompanied media files, the part of the model if any to be animated and general info such as title, description and tooltip content. The main challenge faced while developing this tool was to match virtual information such as tooltips and 3D model parts to the position of the actual equipment. Issue that needs to be considered is the lack of internet connection at places where the LSAs are located. To address these issues, two different approaches were followed. The first one was to install a QR code to a specific location acting as the reference point zero of the virtual environment. Each virtual information would be spawned at a specific offset to all three axes from the point zero. To accomplish this flow, the maintenance scenario JSON model was extended to add offset information for each step declared in it. This approach works under both online and offline conditions.

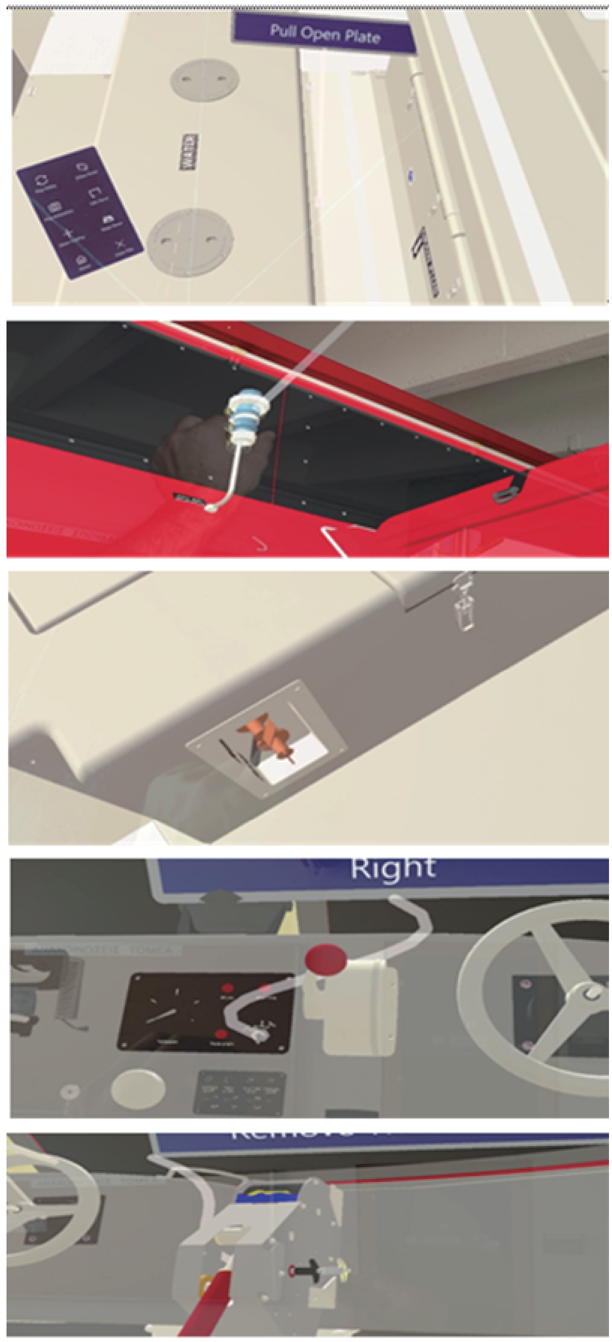

Figure 4 Various interactions with model parts.

The other approach was to create and use Spatial Anchors at designated locations linked with LSA equipment used in the maintenance procedure. For each generated step, the Anchor ID was stored in order to be restored later and to be used as the location for spawned virtual objects. Even though Spatial Anchors approach requires Internet connection to work, it provides a much easier way to generate content for maintenance scenarios compared to the QR approach that requires taking direct measurements for all three axes from the physical QR code installation location for each step. The first step of the Maintenance Tool is to locate and scan the pre-installed QR code in the area of the maintenance (Figure 7). QR code detection loads the corresponding maintenance scenario file and generates the declared scenario steps. The virtual content of the step is spawned using either the Spatial Anchor (if any) or the designated offset (Figure 8).

Another important difference between the Maintenance Tool and Training Tool workflow is the procedure for detecting whether a scenario step has been conducted. In the Training Tool, the hand gesture and the hand interaction with the 3D model part is detected and analyzed in order to decide whether an action has been conducted. On the other hand, while using the maintenance tool, no direct feedback is provided when an action has been performed. Therefore, another button was added to the hand's menu that must be pressed by the user to indicate that the action has been performed.

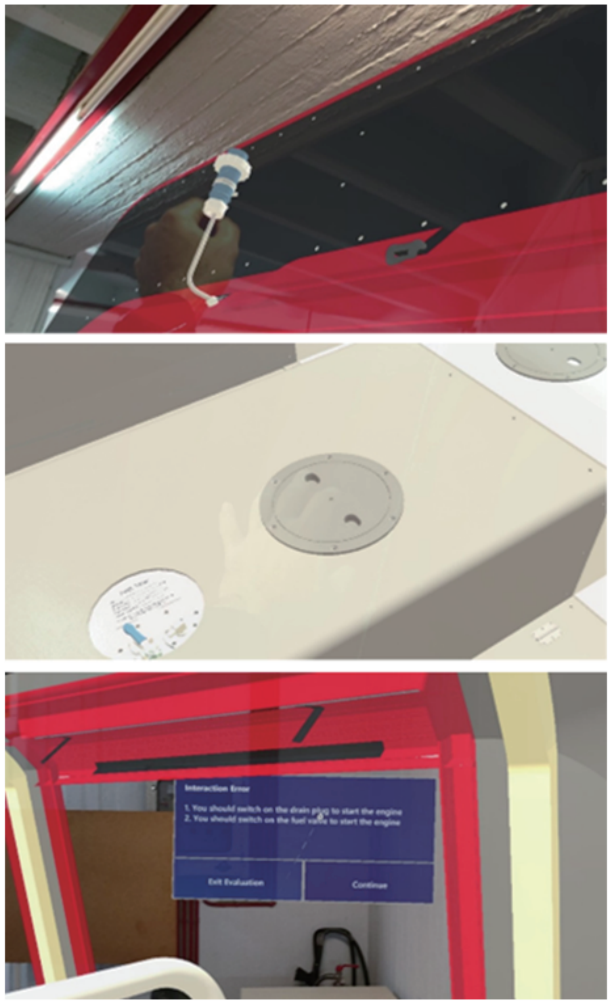

Figure 5 Various interactions with model parts.

4 Results and discussion

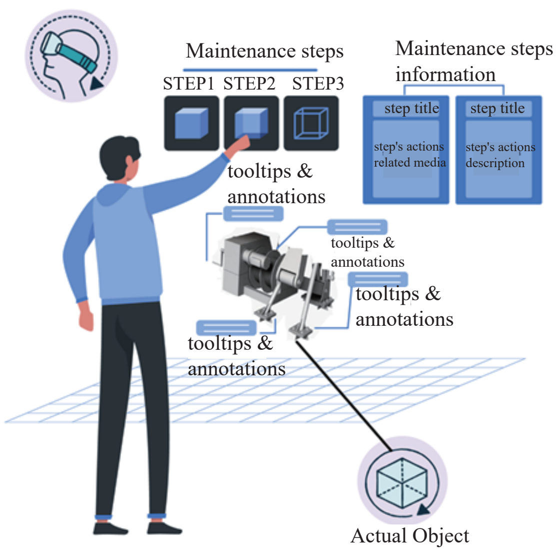

Figure 6 Maintenance tool mockup[11].

Following the methodology described in the previous section, the AR Training application was developed, enabling a 3D-assisted training in MR environment, regarding the use of lifesaving equipment in various scenarios. The training workflow contains all the basic steps of using the equipment, while the application also provides an action step list that must be completed regarding the maintenance procedure of said equipment. The main functionalities provided by the applications are the selection of training scenario, the 3D-model positioning in space, the provision of animations, tooltips and interactive MR menus that support media files, the support of realistic interactions with 3D-model parts, the QR scanning and the generation of MR world. With regards to the validation of its operation and general performance, the application was initially tested in lab environment, using given training scenarios

Figure 7 Maintenance scenario load through QR code scan.

and LSA 3D model. Maintenance scenarios were also generated and tested in lab environment to validate the MR world generation from the QR scanning and the anchors position accuracy. Additionally, the maintenance scenarios provided were also tested in ship environment using the positions of ship's installed LSA equipment.

Further to the validation in lab environment, the MR Training application was tested and validated using a real LSA lifeboat through a dedicated validation campaign that was conducted at the Viking Safety Academy training facilities in Greece. As part of this campaign, LSA training and maintenance sessions were conducted with the participation of volunteers and Viking Safety Academy's operational and skilled personnel, using the application and interacting with the LSA 3D models. The volunteers that participated in this demonstration, either trainers or individuals related to LSA procedures, were able to assess the AR Training application, evaluate its performance and give feedback to the technical partners. Additionally, the application tools were successfuly demonstrated to relevant stakeholders of the SafePASS project and externals in various workshops and demonstration activities, allowing participants to test and evaluate the AR/MR applications. One of them was conducted during the pilot demonstration of SafePASS project that took place onboard Royal Caribbean cruise ship that was constructed at Chantiers de l′Atlantique shipyard, in Saint Nazaire, France. The pilot demonstration was performed during the dry-docking process, when the construction was in its final stage and the ship was ready to sail.

In all testing and evaluation campaigns, the criteria used for assessing the applications were the completion of task and the motivation and user experience. The completion of task refers to the following three different types of scenarios: (1) the completion of one training scenario; (2) the completion of one training evaluation scenario; and (3) the completion of one maintenance scenario. All of them were assessed by observing the time of completion of the respective scenarios. In parallel, the motivation and user experience were assessed using a questionnaire for the training and evaluation tools, while feedback was received by participants with LSA experience via interviews for the maintenance tool. Four different groups of participants were identified based on their experience on LSA operation and MR usage, namely: (1) Group 1: participants with both LSA and MR experience; (2) Group 2: participants with LSA experience, but no MR experience; (3) Group 3: participants with MR experience, but no LSA experience; and (4) Group 4: participants with neither LSA, nor MR experience.

It shall be noted that the maintenance tool was tested and evaluated only by participants of Group 1 and 2, since it required previous knowledge on LSA operation and LSA procedures. For each participant, the time required for scenario completion was measured. In this case, the evaluation feedback was collected through unstructured interviews, allowing more interactive discussions and increased flexibility in the extraction of outcomes. On the other hand, the training tool and the training evaluation tool were tested and evaluated by participants from all groups, since no dedicated expertise or background was required for their operation. For this purpose, dedicated questionnaires were used, in order to extract the perspective of participants regarding their motivation and overall experience. The number of participants and the time required for the completion of scenarios per group are summarized in Table 1.

One of the challenges faced was that not all participants were familiar with the HoloLens 2 HMD. Once users were familiarized with the device and gestures, they were able to complete all tasks from the created scenarios. This led to remarkable differences in the time required for scenario completion among the groups, based on the previous experience of participants on MR usage. Moreover, the LSA experience provided a notable advantage to the relevant participants that were familiar with the equipment and the procedures. As it can be seen in Table 1, participants of Group 1 with both LSA and MR experience required significantly less time for the completion of scenarios that was almost 1/4 of the time needed by participants with no relevant experience. In general, these times cannot be directly compared with the ones required for typical training sessions, since the latter include complex and time-consuming actions related to the actual launching of LSA that cannot be realistically demonstrated through the MR application in terms of complexity and duration. However, a comparison of the time required for simpler actions such as opening of door/valve cover or turning some handles between the MR app and typical training sessions is feasible, leading to similar results.

With regards to the motivation and user experience, the main outcomes from the feedback received by the users are that a flow that would allow them to easily familiarize with the device is recommended. Additionally, wearing and using HoloLens 2 for

Figure 8 Maintenance scenario virtual content in LSA.

Table 1 Number of participants in the testing and evaluation campaigns and time required

Group	Number of participants	Time required for completion of training and training evaluation scenarios (min)	Time required for completion of maintenance scenario (min)
Group 1	2	5–8	15–40
Group 2	5	17–22	15–40
Group 3	7	13–16	–
Group 4	11	23–30	–
Total	25	5–30	15–40

max time of 25–30 minutes and no view to a direct light source are recommended. Moreover, some interactions in the interior of the lifeboat were difficult to perform due to partial occlusion of the application menus and messages. This was mainly due to the level of detail and materials of the Minima 88 3D model. At this point, it should be highlighted that an AR/MR digital twin provides benefits for a training before or during carrying out working task. It provides episodic memory, which is expected to increase learning effects among users/learners. However, digital twins are time- and resource-intensive during their creation. In addition, their use is often limited to only a specific training case. Furthermore, "complex" interactions although valuable and useful they were hard to perform on parts that have small size, which is reasonable considering the small surfaces that detect collision with the hand while operating "complex" hand gestures and moves. On the other hand, positive feedback was received regarding the overall added value of the application.

In general, the experience for the users was by far more interesting than the traditional training procedures. The users also indicated that it is of great value that they can directly practice the knowledge gained from procedural information, while the goal to provide training for "everyone everywhere" was considered achieved. Besides the positive comments received, recommendations for future exploitation were also provided. The most important future exploitation proposed was the expansion of the MR Training application to other evacuation systems apart from LSAs, such as liferafts and mass evacuation systems. This would be of particular interest, since this type of LSAs are deployed physically even less frequently that the lifeboats. Moreover, in this way, the applicability of the application can be significantly broadened, enhancing the awareness of users on equipment usage and maintenance. As a result, the preparedness of crew members during an evacuation is increased and the overall evacuation performance can be improved.

5 Conclusion

Summarizing the above, this work focuses on the utilization of AR technology for training purposes in maritime sector and in particular on the operation and maintenance of LSA lifeboats. A dedicated MR Training application has been developed as part of SafePASS project, aiming to train crew members on the usage of lifeboats and assist them during the execution of maintenance activities and procedure, as well as to support trainers to evaluate the performance of trainees. Through MR, a hands-on experience is provided improving the user interaction with the lifeboat and thus enhancing the overall training process. In this way, the crew members can practice the theoretical knowledge as frequently as needed, get familiar with the equipment they will be asked to operate or maintain and be more prepared in case of an emergency. Additionally, the training evaluation process is improved, allowing the safety trainers to assess the trainees' performance and evaluate the effectiveness of training courses. The MR Training application has been tested and evaluated in lab environment and in training facilities reaching a TRL 7 level for its training and evaluation components and TRL 6 for its maintenance part since further evaluation is required for on board applications.

The MR training application has successfully achieved its goals to provide a training environment for "everyone" and "everywhere" regarding LSA lifeboats emergency and maintenance procedures. Training performed in any desired location solves many issues of the traditional training procedures. Augmented Reality has been validated as a technology capable of performing well in a sector where Virtual Reality is considered the most popular. Trainers and users found the training approach through MR experience far more interesting and more interactive than traditional training methods. Although handling HMD and performing actions with it required a learning curve for inexperienced users, the results show that value is added in remembering procedures. Nonetheless, the application still has room for improvement and areas to be evaluated and validated. For example, the simulation of crowding and other stress factors during evacuation procedures or the response of HMD in open spaces with different weather conditions for maintenance procedures can be taken into consideration for further study and investigation. Finally, future work should include developing a Content Management System (CMS) that will make training and maintenance scenario creation and editing easier for relevant stakeholders.

Declaration of competing interest

We declare that we have no conflict of interest.

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