AR Crew Rescue Assistant and AR Passenger Assistant Application for emergency scenarios on large passenger ships

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Abstract— **Evacuating a large passenger ship is a safety-critical, complex and time-dependent process that requires enhanced situational awareness and efficient coordination of thousands of passengers and crew personnel. Not only the fast and accurate evaluation of ship's condition is of great importance, but also the fast and appropriate response from both the crew and the passengers is crucial to ensure timely and safe evacuation. During an emergency, the evolving nature of a hazard may require adaptation of the exiting evacuation process, while it is not ensured that all passengers are able to comprehend and follow the given safety instructions. In addition, crew's ability to provide clear and accurate instructions to the passengers may be affected by the changing conditions during an emergency and the limited available information from the ship's areas affected. In response, a system that will provide clear instructions to both crew and passengers and guide passengers safely on how to react in an emergency situation is of paramount importance for any large passenger ship. While Augmented and Virtual Reality technology is constantly growing in several application domains such as health, manufacturing, education, safety training and retail, its full potentials for the use in real environment of large passenger ships for training and safety applications has not been exploited yet. In the context of the SafePASS project a set of AR applications has been designed and implemented in order to assist and enhance already existing emergency procedures and tools for large passenger ships.**

I. INTRODUCTION

The evacuation process of large passenger ships involves the mustering phase, which is the process of reallocating passengers to a predefined safe area on board (called muster station) and the abandonment phase which involves the embarkation and launching of lifeboats. Each phase of the evacuation process requires the management of large crowds and comprises a complex sequence of actions depending on the type of incident, while unknown inaccessibility problems exacerbated by incidents such as progressive flooding, fire and smoke may impact the evacuation process [1]. Moreover, the instructions provided by the crew and perceived by the passengers as well as the individual reaction times and performance of pre-evacuation activities are important aspects to be considered in large passenger ships emergency scenarios [2]. Most passengers are usually unfamiliar with the layout of corridors and various spaces on the ship, especially in large cruise ships, which can cause difficulties in locating assembly areas [3]. The current IMO framework for evacuation analysis is formed in MSC.1/Circ.1533 [4], with the “Revised Guidelines on evacuation analysis for new and existing passenger ships”, which makes the assessment of passenger ships evacuation plans through escape routes compulsory, by computational means, during the design phase. This does not yet take into account the presence of location based dynamic evacuation routes calculations that would allow alternative and different evacuation route plans. These include dynamically allocating muster stations, directing passengers directly to embarkment of lifeboats, lateral evacuation across vertical zones of the vessel or evacuation of a ship at port. Currently information about the evacuation routes and the muster stations in case of an emergency, is provided by the safety leaflets available inside the cabins and on corridor walls and some cruise lines play safety videos coving the evacuation procedures over the in-cabin television system. In addition, the International Convention for the Safety of Life at Sea (SOLAS) requires that a muster drill must be conducted by the ship within 24 hours of departure [5]. This information is both static (does not represent the actual challenges and dynamic conditions expected in a safety related incident) and difficult to grasp (as it presents a combination of originating deck-level paths, cross-deck vertical movement and finally the route to be followed at the muster station level deck). Furthermore, in cases of a real emergency scenario, the combination of factors such as, stress and lack of language understanding makes this information difficult to apprehend. The SafePASS project [6] develops an integrated system that collectively monitors, processes and informs during emergencies both crew and passengers of the optimal evacuation routes, coupled with advanced, intuitive and easy to use Life Saving Appliances (LSA), resulting to a significant reduction of the total time required for ship evacuation and increased safety. It is an integrated solution that provides passengers tailored evacuation assistance, assists the crew by enhancing their situational awareness and ability to handle deskilled equipment, while incorporating fail-safe processes for the evacuation procedure.

Augmented reality (AR) 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, including visual, auditory, haptic, somatosensory and olfactory [7]. Recent advances of Augmented Reality (AR) and

Virtual Reality (VR) technology, have made this technology attractive for the cruise line industry. The AR and VR applications in the cruise line sector are mainly related with enhancing the passenger experience on-board i.e., using AR virtual excursions [8], or in providing virtual reality gaming for cruise passengers [9]. In SafePASS, the developed mobile AR applications are targeting both the guidance of crew personnel as well as the assistance of passengers in case of evacuation of large passenger ships in order to alleviate the aforementioned complexities of evacuation process and to address the dynamic conditions of incidents.

The purpose of this paper is to provide an outline of how each AR subsystem performs and interacts with other components to fulfil its end goal. The other SafePASS components are treated, to the degree that it is possible, as opaque entities. The document also offers a presentation of the design and implementation process adopted, the implementation details, as well as the initial testing and validation results.

The rest of this document is organised in four major sections. Section II is the Application Architecture chosen for the development of the AR components and the interoperability with other components. It also provides a description of the AR components' behavior. Section III presents the Application Design choices made for the application modules. Lastly, Section IV offers a conclusion to the topic along with a discussion on the pilot performed and challenges faced.

II. APPLICATION ARCHITECTURE

There are two main use cases for the applications: sending and receiving information (periodically to and from the Core Engine, receiving data from Azure services or device storage) and navigating the application user through a route.

Azure service is an external set of services provided by Microsoft to be used by HoloLens 2 [10] but is also available on other platforms as well. These services are required in order to save and retrieve spatial anchors created to assist the navigation use case. The Augmented Reality Applications' use cases are presented in Figure 1.

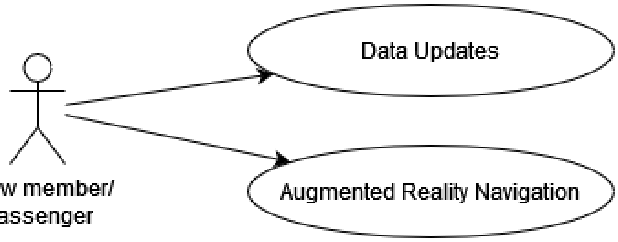


Fig. 1: Augmented Reality Applications' use cases

A. Physical Architecture

The AR mobile applications share the same core architecture and they both have interfaces with the Core Engine of the project (WiFi) and the BLE beacons [11] (Bluetooth).

The Core Engine block refers to the component of the SafePASS system that is the main messaging hub (broker) responsible for the intercommunication between the different components.

The solution proposed in the SafePASS project offers a personalized version of the Location-based Dynamic Evacuation Route (LDER), as calculated by the crowd simulation models of the relevant module which also consider the availability of different route segments based on ship sensor readings.

The Crowd Simulation module receives information pertaining to the current situation and uses it to execute simulations and produce dynamic evacuation routes. Additionally, the Crowd Simulation processes information like sensor data, ship orientation, fire, and flooding incident propagation. The simulation consists of agents, which represent individuals in a crowd who move through a network of movement spaces on a virtual representation of a ship.

The personalised LDER route is offered through a mobile-based application and is relevant to the current location of the passenger as calculated by indoor localization techniques (with the assistance of Bluetooth Low Energy (BLE) beacons). It provides a tailored evacuation plan for each user based on their surrounding situation and events and takes account their current position in the calculation of the proposed path.

An AR feature allows additional visual information overlaid on existing scenery to guide evacuation. The application, through its back-end user interface, supports the officers of the ship in assessing the situation, offering an overview of the progress, allowing them to drill down into details such as the evacuation progress per safety zone, the passengers already mustered etc.

The AR applications are implemented for mobile devices using the Unity game engine [12] and have two wireless interfaces:

- Wi-Fi to connect to the vessel's access points and communicate with the Core Engine for route information and passenger data and the Azure services to receive spatial anchors used for way-finding.
- Bluetooth to connect to the beacons installed and receive positional information.

B. Component Behavior

In the context of the project, two Augmented Reality (AR) mobile applications have been developed to assist the crew members and the passengers at critical situations:

- SafePASS AR Crew Rescue Assistant Application (ARCA).
- SafePASS AR Passenger Assistant Application (ARPA).

1) AR Crew Rescue Assistant Application: When a crew member user activates the device, he/she has to sign in. The application sends both the user's identity and his/her current position to the Core Engine, subscribes to the rescue event listener, and queries the Azure services for nearby anchors. Then, the application listens for a rescue event. When an event arrives, the application displays the information related to the passenger in need of assistance, queries Azure services for spatial anchors related to the route, calculates the current position and sends the data to the Core Engine. When the user (crew member) is ready, the navigation has to be activated and the route has to be calculated. The application generates and displays the augmented directional features along with a map overlaid with the route.

Main features:

- Send location updates.
- Receive passenger position and related information.
- Navigate to passenger in need of assistance.

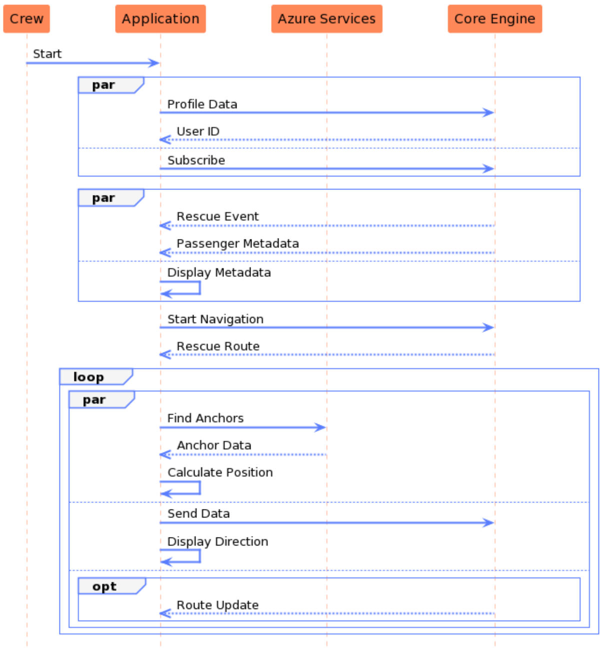


Fig. 2: AR Crew Rescue application sequence diagram

2) AR Passenger Assistant Application: The Augmented Reality Passenger Application enables the monitoring of passenger location. When the application gets activated it gives the passenger the option to request a personalized evacuation route. When the request is applied, the application sends the user identity and current position to the Core Engine, subscribes to the request route event listener and queries Azure services for nearby anchors. Since an evacuation route is provided the navigation is activated. The application generates and displays the augmented directional features along with a map overlaying the current assigned route.

Main features:

- Send passenger location.
- Guide a passenger through a route.
- Receive updates regarding the route.

III. APPLICATION DESIGN

The applications which provides AR navigation features both for the crew and passengers respectively is presented in the form of a proof of concept. They are utilizing the Bluetooth Low Energy (BLE) indoor localization system of SafePASS and a common frame of reference for enabling the navigation based on digital anchors in the AR space mapped to the physical environment, taking into account the orientation relative to the environment. The indoor localization system and the use of digital anchors proved to fulfil the main scope of the applications, which is also the most complex and challenging one.

Fig. 3: Kontakt beacons

Environment	indoor & outdoor
Expected Accuracy	5-10 meters (room-level)
Reliability	sensitive to multi-path obstruction to Line-of-Sight (LOS)
Range	50m (100m max)
Latency	3sec
Battery Life	up to 50 months

TABLE I: BLE characteristics.

Since the applications developed are very similar, analysis is provided only for the Crew application variant for simplicity reasons.

The development and implementation details of the first prototype applications are presented. Due to the challenging and complex task of indoor positioning and navigation, and the limitations imposed by the current state-of-the-art, research on various aspects of the application and several testing activities required for the application development prior to the actual implementation have taken place, as explained below:

- Suitable Bluetooth Low Energy (BLEs) beacons were acquired (Figure 3) based on the indoor localization solution identified.
- Testing connectivity among BLEs and mobile devices in order to get the best positional results.
- Research on use of markers as a mean of reestablishing visual tracking when it is lost.
- Research on use of spatial anchors as means to link real ship compartments with AR features that are used as directional indicators.
- Integration with SafePASS Core Engine with regards to the exchange of messages.

A. BLE localisation

Knowing one's position with significant accuracy, is of paramount importance in complex safety-related procedures. Given that satellite positioning signals are not available inside a ship, several techniques have emerged so far in the cruise industry. Such techniques aim to achieve a compromise between privacy, operational efficiency and ease of use.

There have been a couple of tests conducted [13] to examine the localisation goal in terms of accuracy, which for this type of technology is around 5m. First, the BLE indoor localization system with room-level accuracy was explored [14], focusing on an easy installation procedure that can be followed from non-technical staff, as well as at low cost, so that it can be widely adopted. The system operated by tracking a carried device based on the processing of RSSI (Received Signal Strength Indication) fingerprints from BLE beacons placed in the area (Figure 4). Second, a model using the trilateration algorithm.

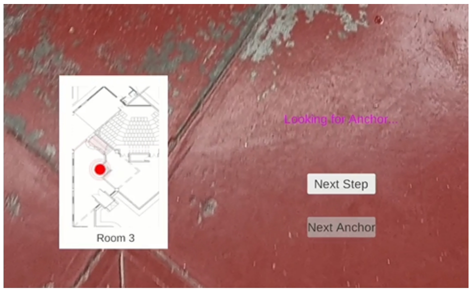
```
iBeacon 31003 21478 TxPower: -77dBm RSSI: -80dBm
iBeacon 55938 17214 TxPower: -77dBm RSSI: -76dBm
iBeacon 41985 61266 TxPower: -77dBm RSSI: -87dBm
iBeacon 55938 17215 TxPower: -77dBm RSSI: -87dBm
iBeacon 22509 27798 TxPower: -77dBm RSSI: -75dBm
iBeacon 48547 10961 TxPower: -77dBm RSSI: -81dBm
iBeacon 31003 21478 TxPower: -77dBm RSSI: -77dBm
iBeacon 31253 40614 TxPower: -77dBm RSSI: -72dBm
iBeacon 55938 17213 TxPower: -77dBm RSSI: -81dBm

Position x:        0.336
Position y:        -0.367
Closest beacon:    mvKsfl
```

Fig. 4: Raw measurements using BLE beacons

1) Fingerprinting: Fingerprinting can be generally divided into two phases: an offline phase and an online phase. The offline phase involves building the signal strength database and creating the signal strength map. After measuring the received signal strength from each visible beacon, the mean value of the signal strength and the distribution of signal strength of each reference point will be calculated and stored in the database. During the online phase, the module chooses the reference point in the database whose signal strength has the minimum difference from the received signal strength of the device as the most probable location. The use of this method needs to balance the accuracy and time-commitment for collecting data when creating signal strength database.

2) Trilateration: The trilateration technique [15] is more flexible as the system calculates device location in real-time and the system is more adaptable to environmental change than fingerprinting. The trilateration algorithm does not need an offline phase like fingerprinting. However, trilateration still needs an accurate beacon location database, including accurate coordinates and the unique Media Access Control (MAC) address for each beacon. During active measurement, after calculating average signal strength for each visible beacon, the system uses this value as an approximation for distance to trilaterate the device's location.

Because of limitations imposed by other SafePASS components, a room-level localization method would not fit, so the selected solution was a technique involving a Kalman filter for the beacon readings and trilateration for the final calculation of position. In Fig. 5 is a view from the application that shows how the indoor position is displayed on a blueprint of a floor that has been carefully measured.



Looking for Anchor...

Fig. 5: Part of the application UI that displays a minimap with indoor position

B. AR tracking

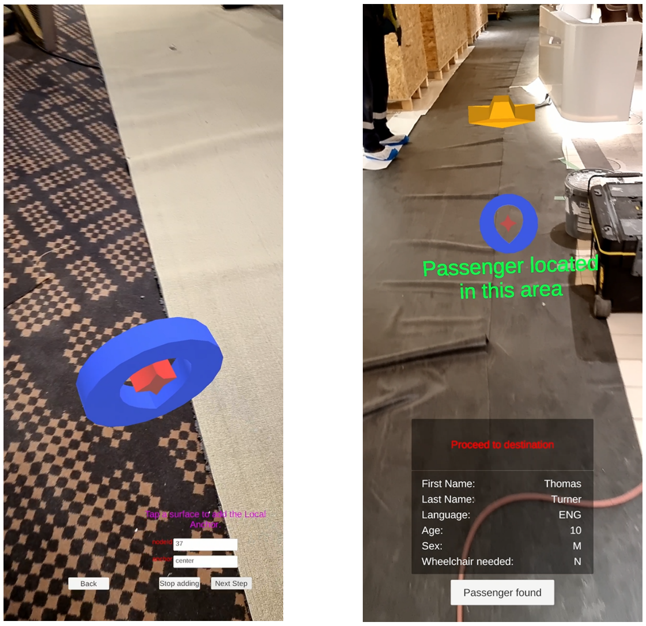
AR tracking is based on a process called SLAM (simultaneous localization and mapping) used by the device to understand where it is, relative to the world around it. Visually distinct features in the captured camera image called feature points are detected and used to compute the change in location. The visual information is combined with inertial measurements from the device's Inertial Measurement Unit (IMU) to estimate the pose (position and orientation) of the camera relative to the world over time. An AR system can look for clusters of feature points that appear to lie on common horizontal or vertical surfaces, like tables or walls, and makes these surfaces available to the app as planes. Because feature points are used to detect planes, flat surfaces without texture, such as a white wall, may not be detected properly. In an environment like a ship, it is very probable not to have enough visual information to distinct among all the different similar areas, hence the usage of visual markers (QR codes) was explored. A unique marker is assigned to each room and be used as a starting point for the AR session in place of the usual plane tracking.

Spatial anchors [16], have been tested and are used for the AR navigation application in the following sense. Spatial anchors are carefully selected to be placed at strategic points of the layouts to be used (i.e. within the ship). Once the evacuation route of the passenger is received on their AR Passenger Assistant application or once a personalized route for assisting passengers in need is received by the Crew Rescue Assistant application, the navigation application uses those virtual anchors that are stored and are associated with the real space, for navigation purposes to the desired location (Figure 6). In addition, a combination of spatial anchors with additional marker-based navigation features further supports the initiation of the navigation process.

Navigation solution The proposed navigation solution consists of various steps about the creation and storing of the spatial anchors.

Based on these steps, we can identify an online and an offline phase. The offline phase of the algorithm is when the user does an initial AR scanning of the area, places the Spatial anchors and stores them on the Azure service. To perform the steps below, specifically storing the text description for each anchor, we used an external service from Google Firebase to setup a backend with REST API that would hold this required information and serve it to the application when needed.

- A new spatial anchor session is created and started. During this process, the device is scanning for AR planes so that it can initialise the spatial anchor session and create anchors on detected planes.
- In order to bind the anchors to the 3D world, the user captures with the camera as much of the surrounding environment as possible by moving and scanning the area around the anchor from multiple angles.
- The user inputs text description (based on a determined naming scheme) for each anchor that helps with the creation of the final navigation path.
- When the system has gathered the necessary information and its knowledge level of the area is high, it allows the user to save Spatial Anchors on the cloud sequentially and the Azure service maintains their spatial relationship.



Tap a surface to add the Local Anchor.

nodeId: 37

anchor: center

Proceed to destination

First Name: Thomas
Last Name: Turner
Language: ENG
Age: 10
Sex: M
Wheelchair needed: N

Fig. 6: Screenshots from the mobile application: (a) Offline scanning phase, (b) End of Crew member navigation (from Pilot)

After communicating with the Core Engine, the application retrieves a generated route by other SafePASS systems and creates a list of Spatial Anchors that corresponds to this route based on the naming scheme. By automatically enabling each anchor of the list in order, the user can be navigated to the destination.

The online phase is when the user wants to navigate to some place after the above-mentioned procedure:

- A new session is created to do the anchor query.
- By doing one more scan of the area and its relevant QR code, the previously placed anchors are retrieved via queries and navigation markers are spawned in the original Spatial Anchors' positions.

IV. DISCUSSION & CONCLUSION

In this paper we proposed an AR application that can be implemented in two different instances, both for crew and passengers, to facilitate the evacuation process of large passenger ships. The aim was to integrate the AR application in the overall SafePASS system and to demonstrate how AR indoor navigation technology can assist crew and passengers in emergency situations onboard of large and complex cruise ship infrastructures.

A pilot demonstration was conducted onboard a Royal Caribbean Group cruise ship at the shipyard of Chantiers de l'Atlantique in February 2022, where the SafePASS solutions were demonstrated in a real environment based on predefined scenarios. As part of the demonstration activity, the instance of the implemented AR Crew Rescue Assistant Application was tested and validated. The scenarios where the AR application was demonstrated included the (i) assignment of a crew member with the AR application to assist a passenger in need (ii) the navigation of the crew member to the location where the passenger in need was located using the AR navigation (iii) the sending of the confirmation message by the crew member to the control center that the passenger is found and is being assisted. The functionalities of the AR application were successfully tested in several ship locations, at corridors outside of the cabins and open spaces.

The main challenge identified during the tests is the dependency of the AR technology on the ability of a mobile device to localise itself using the camera image input by recognising feature points on this image. In the corridor sections of the ship, the visual pattern is repeating without notably distinct feature points. This affects the system's performance to accurately detect its position and movement and therefore impacts the AR navigation. To this end, we intend to analyse the limitations imposed by the corridor infrastructures and conduct further research to improve the feature extraction mechanism so as to optimize the AR navigation performance in such environments.

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