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Overview of people localization systems for safe evacuation of large passenger ships

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Abstract

Maritime disasters in recent years are a stark reminder of the imperative need for timely and effective evacuation of large passenger ships during emergency. Tragedies at sea, notably the 2014 South Korean ferry Sewol and the 2012 Costa Concordia incidents, have magnified the urgent need for improvements in the mustering, evacuation, and abandoning procedures, and have led to a series of new global safety initiatives and measures. Driven by this need, several technologies and systems for people localization have been considered, studied and demonstrated over the past decade, which would enable tracking of passengers and crew either on-board, in case of an emergency in order to improve mustering, evacuation, and abandoning procedures, or overboard, after ship abandoning. In this work, we present an overview of these initiatives, evaluating various aspects of such systems, their advantages and disadvantages. Key factors that are considered in our study have been retrieved after extensive analysis of end-user data, acquired over the past three years in the framework of the Lynceus2Market EU funded project (H2020), which has brought together European global players in the field aiming at implementing the first market replication of these technologies and products.

Keywords: evacuation procedure; safety localization system; emergency monitoring; decision support.

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Nomenclature

API	Application Programming Interface
BLE	Bluetooth Low Energy
CCTV	Closed Circuit Television
CLIA	Cruise Lines International Association
DSS	Decision Support System
ECC	European Cruise Council
EU	European Union
IMO	International Maritime Organization
IoT	Internet of Things
ISM	Industrial Scientific Medical
L2M	Lynceus2Market
RF	Radio Frequency
RFID	Radio Frequency Identification Device
RSSI	Received Signal Strength Indicator
RTLS	Real Time Localization System
SOLAS	Safety Of Life At Sea
SWOT	Strengths Weaknesses Opportunities Threats
TRL	Technology Readiness Level
UAV	Unmanned Aerial Vehicle
UWB	Ultra Wideband
WSN	Wireless Sensor Network

1. Introduction

Maritime disasters in recent years are a stark reminder of the imperative need for timely and effective evacuation of large passenger ships during emergency. Tragedies at sea, notably the 2014 South Korean ferry Sewol and the 2012 Costa Concordia incidents, have magnified the urgent need for improvements in the mustering, evacuation, and abandoning procedures, and have led to a series of new global safety initiatives and measures. Shortly after the ship went aground off the Italian coast with the loss of 32 lives, CLIA and ECC launched a Global Cruise Industry Operational Safety Review. One of the issues identified in the review was the difficulty faced by both crew and rescue bodies when trying to locate people during the evacuation and abandonment of a ship; a problem that often adds to the number of fatalities in an incident. As passenger ships grow larger, this only makes the issue ever more urgent.

Driven by this need, several technologies and systems for people localization have been considered, studied and demonstrated over the past decade, which would enable tracking of passengers and crew either on-board in case of an emergency in order to improve mustering, evacuation, and abandoning procedures, or overboard, after ship abandoning. In summary, these technologies can be divided into two main technologies. Those that operate by localizing people directly, through visual or biometric methods, and those that locate people indirectly, through devices that people carry. In the former category, systems include the use of CCTV cameras, or biometric sensors, while in the latter, systems use devices ranging from mobile phones to passive RFIDs, BLE or sub-GHz transceivers.

In this work, we present an overview of these initiatives, evaluating various aspects of such systems, their advantages and disadvantages. Key factors that are considered in our study have been retrieved after extensive analysis of end-user data, acquired over the past three years in the framework of the Lynceus2Market EU funded project (H2020), which has brought together European global players in the field, such as cruise ship owners, operators, ship builders, maritime equipment manufacturers, a classification society, industry associations and important technology organizations with the aim to implement the first market replication of these technologies and products.

Based on this information, we therefore present a comparative study that evaluates diverse system characteristics, while at the same time taking into consideration installation and maintenance costs, and retrofitting abilities. Our

goal is to provide an overview of available systems, highlighting both the current technologies and their evaluation criteria, in order to inform on the developments of the basic challenges that have to be considered for building systems for people localization that will create significant impact by saving passenger lives during maritime accidents.

2. Review on technologies for large passengers' ships incidents management

Both the size and the capacity of cruise ships have dramatically increased during the last years, creating new concerns in respect to safety and evacuation. Considering the "post Concordia" safety review recommendation, IMO agreed on draft amendments to SOLAS Reg II-2/13 "means of escape" to extend the requirements for evacuation analysis for all passenger ships and not just for the Ro-Ro passenger ships. Such evacuation analysis, able to evaluate escape routes, is required in an early design stage, and should be able to identify and eliminate congestion possibilities during an evacuation and ship abandonment operation. The IMO under SOLAS Chapter III Regulation 21.1.4 requires that all survival craft shall be capable of being launched with their full complement of persons within a period of 30 minutes from the time the abandon ship signal is given. However, for cruise-ships this regulation stipulates that the thirty-minute timeframe only starts when all the passengers have been mustered with lifejackets donned. As one can see, the process of evacuating a large passenger ship is very complex because it involves the management of large numbers of people on a complex moving platform, while people often have very little knowledge about this procedure. Following these developments, several candidate technologies have been considered for the task. This section presents a review on existing technologies for incidents management in large passenger ships, including evacuation procedure, passenger localization, emergency monitoring and decision support. The existing technologies can be divided into two main technology blocks as these are described in the following paragraphs.

2.1. User Transparent Localization

In this paper, we describe as "User Transparent Localization" technologies, those which operate by localizing people directly, without the need for them to carry any devices. This is a significant advantage both in terms of operational costs, and user acceptance. Such systems have already been considered for many on-shore applications, and there are a few examples of maritime use. We have identified the following two main categories of such systems, described in the following paragraphs:

2.1.1. Cameras

The main concept here is the use of visual sensors, like low-cost CCTV cameras to cover the whole area where people can be located. This is not a new idea, since it has been used for decades in many surveillance systems (Black & Ellis (2006), Black & Ellis et al. (2002)). Recent improvement in this system concept is that people localization is done automatically, using dedicated image processing software, capable of identifying individuals in an area. The technologies behind these systems is described in several published works. For a comprehensive overview, in J.R. Martínez-de Dios et al. (2011) the authors describe various sensor fusion approaches for detection, localization and tracking of mobile objects using camera-based WSN. Most of the work in this field is focusing towards reducing the cost of required cameras, and on the type of image processing algorithms that would enable robust and precise localization of multiple targets.

However, regardless of the technological advancements and the advantages that this type of approach presents for people localization onboard a ship, there are quite a few unresolved issues involved. The less significant of them are relevant to the current state of this technology. It could be argued for example that the reported state of the art (Black & Ellis (2006), Black & Ellis at al. (2002)) can cope with small numbers or small densities of people, which is a scenario irrelevant to large passenger vessels evacuation. Moreover, visual capturing would be challenged when considering a wide variety of emergency scenarios, where low visibility would be an issue due to smoke, fire, or other causes. However, the technical barriers could be considered as secondary, since larger densities of cameras and larger servers could cope with these issues in the future. The primary issues involved with this type of solutions are related to privacy, and user acceptance. The former is a significant issue since there are large areas onboard that cannot be covered due to privacy issues, user acceptance and current legislation. It would not be accepted for example to install cameras in cabins, restrooms, certain recreation areas, or even certain charter cruises.

2.1.2. Human Activity Sensors

This is a relatively new and promising field of research, where new sensing devices can detect the presence of human activity. Ranging from low-cost, low-complexity motion sensors, to smart floors and respiration sensors, these sensing devices seem to have the answer to resolving both privacy issues and localization transparency. However, current solutions still lack in maturity. Reported motion sensing devices using infrared or ultrasonic sensors (L. Wang et al. (2010), P. Wojtczuk (2011)) can detect presence, but are rather unsuitable for localizing and identifying large number of people on-board, both in small and large open areas. More promising technologies include UWB respiration sensors (Yuan Liu et al. (2015)) and smart floors (Contigiani et al. (2014)) which can detect presence using low-cost force sensors. However, none of the aforementioned technologies is yet robust enough nor economically viable for deployment in large passenger vessels.

2.2. User Assisted Localization

With this term, we describe systems that do not detect people directly, but rather localize devices that we expect people to carry, using radio frequency devices. Although this is clear disadvantage with respect to the previous direct localization methods, user assisted localization is the norm for current onboard localization systems, due to technology maturity level and cost efficiency. Moreover, such systems can be used for onboard as well as for overboard localization, which makes them more appealing for maritime applications. Their development is based on the emergence of several innovative technologies like wireless sensor networks, sensor and actuator systems, intelligent data processing and fusion techniques, innovative decision support processes, low powered microelectronics and digital signal processing algorithms. Recently, a number of such systems have been developed for the task, which are usually evaluated against the following metrics:

- Cost: Both the cost of infrastructure and of each device is critical, due to the fact that in large passenger vessels, very large areas have to be covered, and very large numbers of people have to be equipped with wearable devices.
- Accuracy: The accuracy requirements of a localization system depend on the application needs. For some areas (e.g. cabins, rooms) knowing the number of people present would be sufficient. In open areas and open decks on the other hand, an accuracy in the order of a few meters would be required.
- Bandwidth: The available bandwidth for RF localization largely dictates the accuracy of the system. However, bandwidth in wireless systems is a scarce resource, which must be contended for by both localization and communication systems in the area.

User assisted localization systems are often faced with the need to make trade-offs between these three main characteristics in order to satisfy the requirements of a given application. In the following paragraphs, the most popular technologies are reviewed.

2.2.1. Passive RFID

Passive RFID devices are devices that have no internal power supply and rely solely on RF energy transferred from the reader to the tag. Although this method is highly cost effective, since the cost of each tag can be reduced significantly, the bandwidth and range of these passive devices is significantly lower than their active counterparts examined below. This has a significant impact on their use and applicability in localization scenarios onboard large passenger vessels. Since the distance from the reader is limited from a few centimetres to a meter, the density of high-cost readers should be significant if we were to achieve acceptable accuracies. Moreover, in the presence of high densities of people, RFID tags have been reported to present lower robustness. Therefore, the use of passive RFIDs is usually confined to act as complementary to other technologies (e.g. Ekahau's - http://www.ekahau.com) or for other onboard uses like giving access to cabins or performing contactless payments onboard.

2.2.2. BLE

BLE technology is a version of the popular Bluetooth technology, customized for very low power consumption. It is an active technology, requiring internal power supply for its tags, and as such, has a higher cost than any passive RFID device. It operates at the 2.4GHz ISM band, which is can be used globally, and provides a significant bandwidth for localization. However, this band is prone to high external as well as co-channel interference, since it is already widely used by many popular systems like WiFi, other Bluetooth devices, Zigbee, etc.

2.2.3. Sub-GHz Radio

This technology uses a number of RF bands below 1GHz, for example the 433MHz ISM band, or the 868/916MHz bands. As is the case with BLE, sub-GHz systems use active tags. Moreover, the frequency bands used have lower bandwidth, and also face different restrictions of use in different parts of the world. Their main advantage is that they are not highly populated by other systems, but are rather dedicated to IoT applications, as the one considered in this work.

2.2.4. Comparison of Different technologies

The following table summarizes some of the main features of the aforementioned technologies.

Table 1. Comparison of different tag based solutions

Competitive Systems	Passive RFID	BLE	Sub-GHz	Comments
Frequency	RFID	2.4GHz	433MHz, 868/916MHz	
Battery Lifetime	N/A	Up to 2 years	Up to 2 years	Depending on use
Range	Up to 1m	Up to 5m	Up to 10m	Indoors
Tag Cost	Very low (<1$)	Low (<10$)	Low (<10$)	
Reader Cost	Very high (500 – 2000 $)	Medium (<200 $)	Medium (<200)	

Although a thorough evaluation of each technology largely depends on the application, we are able to give some general pointers regarding the applicability of each technology to large passenger vessel evacuation. The passive RFID provides a low-cost tag solution. However, its small range, and the high cost of the readers limits its use to mustering and boarding applications, as this will be shown in the next section. On the other hand, its small range does not make it a suitable candidate for overboard localization applications, compared to active RFID solutions. The latter, namely RFID and sub-GHz solutions have comparable performances in terms of battery lifetime, tag and reader cost. The cost of installation however could be a bit higher for BLE systems, due to their smaller range. The main difference of these systems lies in the use of frequency bands. This has the following consequences. BLE's use of the 2.4GHz makes it prone to interference, particularly in crowded areas, where a large number of devices using the same frequency band is present. On the other hand, sub-GHz systems should be capable of switching frequencies from 868MHz to 916MHz and back, depending on the geographical location of the ship.

3. Review on systems for large passengers' ships incidents management

In this section, we present an analysis of existing solutions for onboard and overboard localization, that use any of the technologies presented in chapter two, as well as the L2M equivalent sub-systems. The competitor products shortly presented in the following paragraphs are organized into two main categories, i.e. i) On-board Localization and Evacuation Support systems, ii) Overboard localization systems and electronics.

3.1. On-board Localization & Evacuation Support Systems

3.1.1. AiRISTA Flow - Ekahau Real-Time Location System

AiRISTA Flow enables a Real-Time Locating System (RTLS), using RFID tags. It offers three types of RFID Wi-Fi tags: passive, active, and semi-passive. AiRISTA Flow gives customers the option of RFID, Bluetooth Low Energy (BLE), GPS, or IR technology. Currently it offers two RTLS platforms. Based on the hardware components and applications, AiRISTA Flow Universal Visibility Software (UVS) or Ekahau Vision software provides an intelligent view into the enterprise for all of the RTLS applications in place. With either AiRISTA Flow UVS or Ekahau Vision the executives, managers, and end users get visibility into the location, condition, and status of assets, people, and workflows plus reporting that can be delivered automatically.

3.1.2. Extronics - AeroScout MobileView Software

AeroScout MobileView provides a simple, yet powerful means of tracking the location, status and condition of assets and people. The web-based software platform has a full range of applications with visualization, reporting, management and automated alerting options, as well as the ability to deliver context-aware visibility data to a variety of third-party applications. MobileView unifies asset visibility data from many sources, such as Extronics Advance‘s Wi-Fi Tags, Wi-Fi clients, Passive RFID, GPS, third-party devices and sensors, and turns this data into automated business processes – delivering a scalable, enterprise-proven software solution.

3.1.3. Sea Hawk Surveillance – Real-time safety solution

The mission of Sea Hawk Surveillance is to provide a real-time safety solution to monitor passengers and the cruise lines personnel with a reusable waterproof RFID wristband device. This wristband device contains state-of-the-art technology that provides a 24/7 monitoring of passengers. It also identifies all persons in the vicinity of any incident and stores all historical information during the cruise. The wristband is an intelligently designed wristband for localization of personnel using RFID technology. The innovative micrometre integrated circuits allow for the wristband's compact, convenient size and ultra-low power consumption. This wristband is integrated within soft, durable material and a rigid waterproof housing. If the wristband is broken or opened without approval or permission, it immediately will send an alarm signal.

3.1.4. AutoCrew - Automated Crew Management System

AutoCrew or “Automated Crew Management System (ACMS)” is an application designed to fulfil a variety of personnel localization and reporting functions within a variety of industrial work sites, and possibly multiple sites working together. The AutoCrew is an IT based solution that provides multiple management stations and unlimited number of readers of RFID tags for real time situational awareness and readiness assessment. The AutoCrew solution helps mustering and boarding, by scanning the tags of crew and passengers at predefined checkpoints.

3.1.5. Nanotron technologies

Nanotron Technologies provides high-throughput real time location systems with wireless transmission of vital data based on WSN technology. These systems are built around their embedded location platform based on chirp spread spectrum modulation, which they have patented for commercial wireless data transmission. The company proposes collaborative localization (relative positioning of the nodes) using time-of-flight (TOF) ranging and a patented technique to avoid node synchronization and fixed localization (localization with respect to fixed points or anchors) using time difference of arrival (TDOA). The latter requires time synchronization of the anchors. This solution may have higher accuracy. However, it has higher energy consumption and uses the already crowded 2.4 GHz frequency band.

3.1.6. SIREVA project

The focus of the SIREVA project is on optimizing the workflow and communication of the emergency on-board organization by providing technical support for the crew member's key functions such as counting and identifying passengers at their assembly stations. The system developed by the SIREVA project is based on localizing wearable Bluetooth Low Energy (BLE) tags within all areas that are equipped with the respective transceivers. Depending on the technical and financial efforts made, the accuracy for locating people varies between an area of e.g. a vertical fire zone on a certain deck and less than one meter. Variable distances between transceivers are used to reflect different accuracies needed: the borders of a muster station must be detected very precisely, while an accuracy of a few meters is enough to ensure that e.g. public spaces are completely evacuated.

3.1.7. Lynceus2Market On-board Localization System

The Lynceus2Market project addresses the challenge of localizing people onboard a large passenger vessel as well as overboard in case of an emergency, through delivering a revolutionary operational system for safe evacuation based on the integration of several innovative people localization technologies and evacuation and safety related systems. The Lynceus2Market on Board system consists of:

- Localizable life jackets that can provide passenger location in real-time during emergency

- A network of gateways that act as the backbone of the localization system, and can also accommodate several fire and safety sensors.
- Innovative localizable bracelets able to send activity data to the emergency management team
- Low cost fire and flooding escalation monitoring sensor nodes
- Novel mustering handheld devices for automatic identification and counting of passengers during evacuation
- Smart localizable cabin key cards
- Intelligent decision support software able to fuse all localization, activity and disaster escalation data to provide an integrated real-time visualization, passenger counting and evacuation decision support

Lynceus2Market bases its on-board localisation on low-cost, ultra-low-power wireless sensor network technology, using signal strength as a perception of distance (RSSI). Measurement of RSSI is inherent to RF communication (a built-in function in the node hardware) and therefore an attractive method. An intelligent decision support software is able to fuse all localization behavioural and disaster escalation data so as to provide real-time visualization, passenger identification and evacuation decision support. It provides real-time information regarding people and crew location, disaster escalation, passenger behavioural information and mustering information.

3.2. Overboard localization systems and electronics

Over board localization systems are responsible for localizing people at sea. All these systems rely on the assumption that people overboard are wearing lifejackets equipped with electronic equipment used for radio localization. The latter can be either life-jacket based, or system based, and utilize one of the following technologies:

a. GPS reception. GPS is excellent for providing a localization accuracy of 10 meters or less at open spaces, where view to GPS satellites is unobstructed. This information is available at the GPS receiver on the lifejacket, but is not available at system level. Therefore, GPS based solutions need to be complemented with a communication system to transmit their calculated position to the search and rescue agency. The cost of this combination is usually high, and therefore GPS based systems target the high end of the market.
b. Radio Beacon transmission. In this setup, life-jackets are equipped with electronic equipment that can either send out a radio beacon, or can respond to radio signals transmitted from search and rescue agencies. This solution is more cost effective than the GPS solution, but is limited in range by the range of the radio equipment.

In the following paragraphs, we present some key overboard localization systems.

3.2.1. AiRISTA outdoor location tracking

AiRISTA uses the same RSSI algorithmic engine together with GPS for overboard localization. The RSSI Engine would require a Wi-Fi infrastructure, while GPS reading would require a communication link to transmit tag readings to a central search and rescue control center.

3.2.2. Extronics - Outdoor Equipment Tracking

Extronics aims to optimize outdoor workflows with greater visibility of open-air work areas. Its solution incorporates an active RFID tag either affixed to a user, while the use of a battery suggests that this is an active RFID system. The active RFID tags send location data in regular, short bursts over an infrastructure network, which means that localization functions are executed on the tags, and would therefore need a number of anchor points for localization and for communicating their information to the backbone.

3.2.3. Sea Hawk Surveillance - Overboard

The product locates personnel using RFID technology through designed wristband. Sea Hawk Surveillance monitoring program receives the data from the wristband via satellite indicating that a passenger is overboard. The ships control bridge is also immediately notified. Sea Hawk NOC immediately starts localizing the person in the water and relaying the information to the ship’s control. The ship’s bridge is also receiving the data from the satellite.

3.2.4. Deutsche Telekom M2M (machine-to-machine) Localization

The product aims to enable machines, sensors and vehicles to communicate with each other or with a central data processing platform. People and objects are localized by GPS and locations are relayed via the mobile network to a control center. Small GPS trackers that fit into a handbag or a jacket pocket relay the wearer's exact position on demand to a control center.

3.2.5. Lynceus2Market Overboard Localization System

The L2M overboard Localisation system consists of two main components; An innovative shore or ship-launched Unmanned Aerial Vehicle for localizing people in the sea in short time and assisting search and rescue operations and a low-cost rescue-boat mounted radar for people localization in the vicinity of the boat. The UAV carries GPS, radio-location, processing and communication modules. Life-jackets are equipped with localizable active reflector tags. The localisation algorithm takes full advantage of two diverse frequency bands in order to achieve both large range and high accuracy.
In the next paragraph the results of a comparative analysis performed in the context of the L2M project, indicating the advantages of the L2M onboard and overboard systems compared to their competitors.

4. Comparison analysis of people localization systems

This section presents a comparative analysis of the existing competitive products compared to the Lynceus2Market on-board and overboard systems Table 2 summarizes the major characteristics of the solutions presented in terms of the employed Onboard/Overboard technology and the capability of integration with native or third-party emergency monitoring systems.

Table 2. Comparative analysis of existing solutions for localization in large passengers ships

Competitive Systems	Onboard Technology	Overboard Technology	Emergency Monitoring System Integration	Extra features
AiRISTA Flow	RFID, BLE, GPS	GPS	Yes	Wide range of accompanying applications
AutoCrew	RFID	n/a	No	n/a
Deutsche Telekom M2M	n/a	GPS	No	n/a
Extronics	RFID, WiFi	GPS	No	Wide range of accompanying applications
Lynceus2Market	RFID/sub-GHz	Sub-GHz	Yes	Passengers health status information
Nanotron	2.4GHz active RFID	n/a	No	No incident management
Sea Hawk Surveillance	Active RFID	Active RFID	No	n/a
SIREVA Project	BLE	n/a	No	No incident management

5. Conclusion

In this paper, we presented a comparative study that evaluates several technological solutions and existing systems for localizing people both onboard large passengers' vessels and overboard. Our goal was to provide an overview of available systems, highlighting both the current technologies and their individual characteristics, to inform on the developments of the basic challenges that have to be considered for building systems for people localization that will create significant impact by saving passenger lives during maritime accidents.
Our study has shown that if we consider the technological and privacy barriers as well as the critical metrics that influence user acceptance (e.g, frequency, lifetime, range and cost) as well as the capability to perform well both onboard and overboard, the Lynceus2Market provides an excellent solution with respect to other existing systems, effectively overcoming the basic challenges that have to be considered for building systems for people localization that will create significant impact by saving passenger lives during maritime accidents.

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