Smart Escape Support System for Passenger Ship: Active Dynamic Signage & Real-time Escape Routing

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Abstract: It is critical that passengers should be given timely and correct escape or evacuation guidance from captain and crews when there are hazardous situations in a ship. Otherwise the consequences could be disastrous as “SEWOL Ferry” the South Korean passenger ship which sank in southern coastal area on 16th April 2014. Due to the captain’s delayed evacuation decision and lack of sufficient number of crews to guide passengers’ evacuation, the accident resulted in many casualties, most of whom were high school students (302 passengers sank down with the ship while 172 rescued).

Key words: Passenger Ship Safety, Active Dynamic Escape Guidance Device, LPWA Wireless Ship Network, Real-Time Escape Routing

1. INTRODUCTION

It is critical that passengers should be given timely and correct escape or evacuation guidance from captain and crews when there are hazardous situations in a ship. Otherwise the consequences could be disastrous as “SEWOL Ferry” the South Korean passenger ship which sank in southern coastal area on 16th April 2014. Due to the captain’s delayed evacuation decision and lack of sufficient number of crews to guide passengers’ evacuation, the accident resulted in many casualties, most of whom were high school students (302 passengers sank down with the ship while 172 rescued).
Building a passenger ship with well-designed physical escape routes is one thing and guiding passengers to those escape routes in real disaster situation is another. Passengers get panic and move to a wrong direction, bottleneck makes situation worse, and even crews get panic also - passive static escape route signage and small number of trained crews might not be enough to take care of them.

SESS (Smart Escape Support System) is being developed sponsored by South Korea Ministry of Ocean and Fisheries starting from 2016 with 4 years of roadmap. SESS comprises multiple active dynamic signage devices which communicate with real-time escape routing server software via LoRa (Long Range) proprietary wireless network.

2. SESS (SMART ESCAPE SUPPORT SYSTEM) USE CASE SCENARIOS

Fig. 2 shows how SESS works when escape or evacuation situation happens in a passenger ship such as abnormal heeling, fire breakout, and water leakage. SESS can be regarded as a kind of closed loop control system which comprises continuous feedback cycle of "Real-time Sensing", "Precise Decision Making", and "Timely Actions".

2.1. Real-time Sensing

There can be 2 ways for gathering crisis event information from sensors - legacy sensor systems integration and new types of sensor network deployment. SESS enables easy-to-install type of new IoT (Internet-of-Things) sensor network deployment by using LPWA LoRa wireless communication technology.

2.2. Precise Decision Making

SESS automatically collects and analyzes sensor data streams to identify abnormality within a ship. When SESS detects an event, relevant data and information are visualized for captain's effective decision making whether escape of evacuation should be initiated or not.

2.3. Timely Actions

SESS reveals its real value when escape or evacuation procedure initiated by captain. As soon as captain presses "Execute Escape!" button, SERA (Safe Escape Routing Algorithm) runs and generates a safe and fast escape route from every passenger location in a ship to designated emergency assembly stations just within a few seconds. Passengers can easily find their way by simply following the "Active Dynamic Signage - Voice & Arrow".

3. TECHNICAL BUILDING BLOCKS

SESS's closed-loop control process involves multiple technical components which require hardware, software and communication resources. LPWA LoRa wireless technology has been tested and proved to be suitable for ship area local wireless network. A new type of active dynamic signage device plays critical roles for sensing events and guiding passengers. SESS uses 3D data model of a ship to visualize event status and to interact with captain and crews. SERA utilizes mathematical network problem solving algorithms to find out feasible routing solutions within a few seconds. SESS also provides visual computer-based escape simulation capabilities to analyze and compare the escape performance under various crisis situations within a passenger ship.
### 3.1. LPWA LoRa Wireless Communication Network

LoRa is a kind of LPWA wireless communication technology competing with Sigfox, NB-IoT, etc. Fig. 3 shows the characteristics of LPWA technology in view of power consumption, data rate, and range.

![Fig. 3 Characteristics of LPWA compared with other wireless communication technologies](image)

LoRa is a patented chirp spread spectrum modulation technology from Semtech Inc. who provides LoRa chipset to the market, while LoRa Alliance - the global open and non-profit association - publishes protocol specification documents.

LoRa uses unlicensed ISM (Industrial, Scientific, and Medical) frequency band with speed of 3~5kbps. The transmit power ranges from 10mW (10dBm) to 200mW (23dBm) in South Korea. For security concerns, LoRa provides AES-128 encryption. The latest LoRaWANTM technical specification document is V1.0.2 which published in July 2016.

Fig. 4 shows the actual on-board test for LoRa range performance in 2016 - South Korean passenger ship “Sea Star Cruise” who sails between Mokpo and Cheju island. LoRa test devices were used for checking PER (packet error ratio) among transceiver and receiver, which resulted in good coverage performance even within spaces surrounded by steels.

![Fig. 4 “Sea Star Cruise” ship specifications and LoRa performance test results](image)

### 3.2. Active Dynamic Signage

Legacy exit signage and low location lighting is passive and static. They are always turned on and just waiting for passengers to watch them during escape or evacuation - so they are passive. Meanwhile, they are always showing same symbols and same color of light, they cannot change the direction of sign and color of light - so they are static.

Imagining the critical role of crews in real escape or evacuation circumstances will be pictured by “as many crews as possible are dispatched to all over the passenger deck”, “the crews are holding megaphone and radio communication device”, “they communicate with captain and each other to clarify nearby hazard and find safe ways to assembly station”, “guide passengers to follow certain lines and passages”. The crews tell and passengers pay attention to them, the crews lead passengers and continuously find and change route to guarantee safe arrival to the assembly station - the crews are active and dynamic.

ADS (Active Dynamic Signage) mimics the crews’ active and dynamic guidance activities. ADS has embedded loud speaker system to tell passenger to do what using pre-recorded voice announcement and guidance messages. ADS can show right (currently safe and fast) escape direction (up, down, left, right) with its front panel LED arrow display and edge-side beam light. ADS can also give warning message (do not enter) and visual sign (red “X” front led display) for passengers not to risk any nearby hazard. ADS has embedded temperature sensor and smoke sensor to identify whether current location is safe or not for passengers to get through. Normally ADS get electric power from AC power line and embedded rechargeable 2,600mA battery guarantees more than 1 hour operation under black-out situation. Fig. 5 illustrates LoRa enabled ADS features and design.

![Fig. 5 ADS (Active Dynamic Signage) - mimics active and dynamic role of crews](image)
3.3. Escape Route Modelling Tool

In order for SESS to be intelligent enough, SESS should aware the whole escape route structure of a passenger ship as well as the individual location of installed ADS devices. The first step of applying SESS is to prepare a 3D model of a ship and construct a database model of nodes and arcs which represent locations of ADS and escape route respectively. The attributes of escape route include length, width, capacity, and etc. which will be used as input data for SERA (Safe Escape Routing Algorithm). Fig. 6 shows example screen shots from escape route modelling tool.

3.4. Monitoring and Application Server System

ADS devices normally interact with monitoring and application server software via LoRa gateway which has LAN connection to server system. The server side software system runs MQTT message broker to communicate with sensors, ADS, and legacy fire & gas systems if necessary. The most critical function of server side system is to analyze sensor data streams and to identify abnormal situation event which will be notified to captain and crews. The server side system also runs embedded SERA module and encodes control packets for each ADS. The server system interacts with visual user interface system as well. Fig. 7 explains major functions of server side software system.

3.5. SERA (Safe Escape Routing Algorithm)

SERA can be described as Time-expanded, Min-Cost, Max-Flow type of heuristic network problem solving algorithm, which maximizes the number of escaping passengers while minimizing the total escape time in the escape route network. The input data include total number of passengers, location of assembly station (final exit), nodes and arcs attributes, and hazardous nodes identified currently. In a given escape routing problem, the travel time of each arc is defined as cost, and flow is defined as the number of moving passengers by using the arc for their escape. Fig. 8 shows an example of nodes and arcs based escape routing network problem. The left most node is a source node, two right most nodes are assembly stations, and the other nodes represents individual location of ADS.

SERA aims to maximize the flow while minimizing the cost in order to move as many people as possible to assembly stations through the available fastest arc if possible. Let’s say there are 100 people to be escaped at Node 1, and Nodes 14 and 15 are assembly stations, and the legacy exit signage leads passengers via route 1-2-5-12-14. Since the capacity of the 2-5 path is three people, two out of five people arriving at the Node 2 are bottlenecked, so that only three people can move to the 2-5 path, and two out of the three people arriving at the Node 5...
can also move to the 5-12 path without being stuck by a bottleneck situation, and only the two people arriving at the Node 12 will be able to head to assembly station by moving to the 12-14 path without bottleneck. In other words, it can be seen that the number of passengers escaped per unit time and total escape time can't be optimized if only the shortest route to assembly station is guided. Therefore, it can be seen that the guidance for the 2-6 and the 5-9 path is required at the same time, suggesting that the Max flow method that maximizes the available arc capacity at the unit time of the disaster situation should be performed concurrently by crews or ADS.

SERA can also generate bottleneck minimizing escape route by time-expanded modelling technique. Even though there are number of high performance network problem solving engines such as CPLEX and Gurobi, their calculation time (around 10 seconds for 98 nodes and 252 arcs) for finding optimal solution cannot be tolerated during the real disaster situation which requires under second level calculation speed. (SERA: below 0.5 seconds)

3.6. Visual Interface System for Captain and Crews

SESS provides 3D ship model based visual user interface software which is able to display relevant alert and escape initiation command to captain and crews. It shows current status of ADS sensor values and device condition as well as user friendly screen navigation functionalities. During the escape stage, it can display current directions each ADS guides and manual status change for specific locations from safe to danger or vice versa is also possible. This user interface software can be used for escape training mode or escape simulation mode also. Fig. 9 highlights key features of it.

3.7. Escape Performance Simulator

There are many kinds of computer-based simulation software for passenger ship escape analysis, which meet MSC. L/Circ. 1533 requirements for guidelines on evacuation analysis for new and existing passenger ships. But, these simulators do not provide features for SESS type of escape scenarios.

Escape performance by applying SESS can be highlighted for the scenarios such as dynamic situation changes which require escape route change and cause bottleneck. Simulation software for SESS should provide functions which enables applying various dynamic disaster event scenarios even in the middle of a simulation process. Virtual passengers' path finding algorithm should also be adapted to SERA results. Fig. 10 shows some screenshots from SESS simulator.

![Fig. 10 3D model based passenger ship escape simulator](image)

4. PILOT ON BOARD EXPERIMENT AND RESULTS

SESS experiment was conducted at "SAEYUDAL" - training ship of Mokpo Maritime University on 4th Oct. 2016 to verify the value of SESS under dynamic emergency escape scenarios. Total 100 participants were divided into two 50 participants groups—comparison group and experiment group (Each group has 42 men, 8 women, 110 day on-board experience). For every escape scenario, individual participant measured his or her own escape completion time with a stopwatch.

Experiment settings are as follows. (Fig. 11)
- 3-8 participants distributed in 12 cabins, which area is surrounded by 4 exit doors
- Normal walking speed when escape from cabins without
talking to each other
- Initial escape notification is given via ship area announcement system
- Start stopwatch when each participant starts to move
- Experiment assistants stand outside of exit door blocked participants as scenarios

From experiment with scenario 1, total time consumed for escape was 64 seconds with comparison group and 40 seconds with experimental group, which shows 38% decrease. (Fig. 12)

Time duration gap to the 25% participants escape was 7 seconds between comparison group and experiment group, which corresponds to 61% decrease. This result implies the SESS can impact greatly for the early stage of escape. This implication can also be found from the number of escaped participants within 20 seconds was 17 (comparison group) vs. 31 (experiment group).

The results also shows the SESS's bottleneck minimizing capability. 35 participants of the comparison group escaped via EXIT 2 because they preferred to use familiar exit or pre-educated exit before the experiment. Meanwhile,
participants of the experiment group used all of 4 EXITS quite evenly.

Scenario 2 emphasizes the capability of SESS which can automatically generate safe escape route which reflects detected danger from the beginning of emergency. This impact can be found from Fig. 13 – completion time to 25% participants was 30 seconds (comparison group) vs. 20 seconds (experiment group), which means 33% decrease. The number of escaped participants during the first 20 seconds were 4 (comparison group) vs. 11 (experiment group), which shows three times more. Total time consumed for escape completion was 89 seconds (comparison group) vs. 69 seconds (experiment group), which converts to 22% decrease impact. The impact will be greater if the environment is bigger and more complex.

5. CONCLUSIONS AND NEXT STEPS

The objective of developing SESS is to minimize loss of lives. From the experiment above, total escape time could be decreased by 38% and bottleneck could be minimized. The value of SESS could be much greater during the early stage of escape – up to 61% time decrease when crews and passengers prone to get panic. The SESS will be more capable by incorporating multi-type sensor network integration and deployment such as gyro, water, people counting, and etc. The user interface system could be integrated with general ship crisis decision support system. ADS might be required to meet MSC. 1/Circ. 1167-1168 in order to get certification as an alternative escape guidance system to LLL.

REFERENCES

[1] IMO(2016), Guidelines for evacuation analysis for new and existing passenger ships, MSC.1/Circ.1533
[3] IMO(2005), Interim guidelines for the testing, approval and maintenance of evacuation guidance systems used as an alternative to low-location lighting systems, MSC.1/Circ.1168