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Design of Maritime Localization System for Safe Evacuation of Cruise Ships

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Zusammenfassung

Diese Arbeit behandelt den Entwurf von zwei Lokalisierungssystemen mit dem Ziel, ein integriertes System für maritime Anwendungen, wie beispielsweise die sichere Evakuierung von Kreuzfahrtschiffen zu entwickeln.

Für Anwendungen über Bord und das Auffinden von Passagieren wird ein sehr energiesparendes Lokalisierungssystem entwickelt. Dieses System basiert auf der Messung der Signalstärke eines empfangenen Signals (*received signal strength*, RSS), welches von einer in die Rettungsweste integrierten Elektronik empfangen wird. Das Signal wird von einer Basisstation gesendet, welche auf einer fliegenden Drohne montiert ist. Ein neuartiger Algorithmus, welcher eine gewichtete Version der kleinsten Fehlerquadrate (*weighted least mean square*, WLMS) verwendet, wird für signalstärkebasierte Lokalisierungssysteme entwickelt. Damit kann eine Verbesserung der Positionsgenauigkeit um 50% gegenüber der konventionellen ungewichteten Variante (*least mean squares*, LMS) des Algorithmus erreicht werden. In Simulationen wird der Einfluß des Flugmusters der Drohne auf die Positionsgenauigkeit gezeigt. Messungen mit diesem System werden in einem Testfeld mit einer Größe von 500 m × 350 m ausgeführt. Dort befinden sich mobile Stationen, welche mit einem effektiven (RMS)-Fehler von 38.4 m positioniert werden können. Die Meßergebnisse zeigen eine bessere Genauigkeit als es mit herkömmlichen Algorithmen für die signalstärkebasierte Positionierung möglich ist. Weiterhin wurde eine großangelegte Demonstration auf See durchgeführt, um die Funktionalität des Systems in einem realistischen Szenario zu zeigen.

Für das Lokalisierungssystem der Passagiere an Bord des Schiffes wird ein neuartiges, integriertes, subharmonisches frequenzmoduliertes Dauerstrichradar (*frequency modulated continuous wave*, FMCW) präsentiert, in welchem die Frequenz des gesendeten Signals von 24 GHz in einem aktiven Reflektor durch 10 geteilt wird. Ein Prototyp wird entworfen in der GlobalFoundries (GF) 45 nm *Silicon-on-Insulator*-(SOI)-Technologie für die Schaltungen bei 24 GHz und in der GF 0.18 µm 7WL BiCMOS-Technologie für die Phasenregelschleife und den Empfänger bei 2.4 GHz. Die Meßergebnisse für dieses System zeigen, daß das System, im Gegensatz zu konventionellen FMCW-Primärradarsystemen, immun gegen starke Mehrwegeausbreitung ist. In einer Laborumgebung erreicht das System eine Standardabweichung für den Abstand von 3.7 mm. Bei einer Messung in einem realistischen Innenszenario beträgt der Meßfehler für den Abstand 22.3 cm mit einer Standardabweichung von 5.8 cm. Zusätzlich wurden in diesem Szenario auch Messungen mit dem LMS-Algorithmus durchgeführt. Diese Messungen ergaben einen RMS-Fehler von 26.8 cm mit einer Standardabweichung von 2.97 cm. Die Fehler liegen damit deutlich unter denen aktueller FMCW-Lokalisierungssysteme für Anwendungen in Innenräumen. Weiterhin ist damit experimentell bestätigt, dass das entworfene System in der Lage ist, das Problem der Mehrwegeausbreitung von Funksignalen deutlich zu entschärfen.

Abstract

This work presents the design of two localization systems with the aim of providing an integrated system for safe evacuation for maritime industry and cruise ships.

In this work, a low power overboard localization system is developed that aims at providing a system for localizing passengers in case they go overboard the ship. This system is based on measuring the received signal strength (RSS) between smart lifejacket tags and one interrogator station mounted inside an unmanned aerial vehicle (UAV). A new weighted least-mean-squares (WLMS) algorithm is developed for RSS based localization. Both simulation and measurement results are presented. It is shown that up to 50% improvement in positioning accuracy can be achieved using the proposed WLMS algorithm compared to the conventional unweighted least-mean-squares (LMS) solution. Simulations that study the effect of the UAV search path on the localization accuracy are presented. Measurements are carried out in a search area of 500 m × 350 m, where tags are localized with a root mean square (RMS) error of 38.4 m. The measurement results show better localization accuracy compared to other RSS based localization algorithms. In addition, large-scale sea demonstration was performed that showed the system in an operational environment.

For the on-board passengers' localization system, a novel integrated sub-harmonic frequency modulated continuous wave (FMCW) radar system based is presented, where a 24 GHz frequency divider-by-10 is used as an active reflector tag. A practical prototype is designed and fabricated on a GlobalFoundries (GF) 45 nm silicon-on-insulator (SOI) technology for the 24 GHz building blocks, while a GF 0.18 µm 7WL BiCMOS technology was used for the 2.4 GHz phase-locked-loop (PLL) and receiver (RX). Measurement results show that as opposed to conventional primary FMCW radars, the proposed system is immune to strong multi-path interferences resulting from the direct reflections of the interrogating signal. When measured in lab environment, the system achieves a ranging standard deviation of 3.7 mm. Moreover, when measured in an indoor environment, ranging results yield a ranging RMS error of 22.3 cm with a standard deviation of 5.8 cm. In addition, indoor positioning measurements are performed using an LMS algorithm. Measurement results show that the sub-harmonic FMCW radar system has a positioning RMS error of 26.8 cm with a standard deviation of 2.97 cm, which outperforms other state-of-the-art FMCW indoor localization systems. It also further proves the system ability to mitigate multi-path interferences in complex indoor environments.

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Chapter 1

Introduction

This chapter explains the motivation behind this work, gives an overview about the localization systems to be developed and presents the thesis scope, objectives and outline.

1.1. Motivation

The maritime industry is currently facing critical problems associated with the evacuation of passengers and crew-members from ships. This is particularly critical for the evacuation of large cruise ships during emergencies. Even though there are established evacuation procedures to be followed during maritime accidents like flooding or fire, the passengers' behaviour becomes very unpredictable in case of such disasters, which makes it very difficult for crew-members during evacuation.

Despite the huge investment in the construction of new cruise ships, the cruise industry still encounters loss of lives in the sea due to failure to adhere to evacuation procedures and inefficient safety and evacuation plans [LYN]. Tragedies at sea, notably the 2012 Costa Concordia and the 2014 South Korean ferry Sewol incidents, have magnified the urgent need for improvements in the mustering and evacuation procedures, and have led to a series of new global safety initiatives and measures. Shortly after the 2012 incident, the Cruise Lines International Association (CLIA) and the European Cruise Council (ECC) launched a global cruise industry operational safety review. One of the issues identified in the review was the difficulty faced by both the crew and rescue bodies when trying to locate people during the evacuation of a ship, which had added to the increased number of fatalities in that incident.

In Greek mythology, Lynceus was the son of Aphareus and Arene, and the grandson of Perseus. He was one of the argonauts participating in the hunt of the calydonian boar. He had supernaturally keen sight, and could even see things that were under the sea. The project Lynceus2Market [LYN] aims to offer keen sight to our present days argonauts so that they can ensure the safety of the passengers in emergencies irrespective of where they are located, whether on-board the ship or overboard in the sea.

A group of companies and technology organisations involved in wireless technologies, safety, life-saving equipment and the cruise/shipping industry formed a consortium for the Horizon 2020 Lynceus2Market project with the aim of providing a highly integrated system for safe-ship evacuation [LYN]. The proposed Lynceus2Market system offers the following subsystems and products as shown in Figure 1-1:

- Localisable lifejackets that can provide passenger location in real-time during emergency when on-board the ship or when overboard in the sea water.
- Smart smoke detectors that act as communication base-stations (BSs) and anchor points for an on-board localisation system.
- Innovative localisable bracelets able to send activity data to the emergency management team.
- Low cost fire and flooding escalation monitoring sensor networks.
- Waterproofed mustering handheld devices for automatic identification and counting of passengers during evacuation.
- Smart localisable cabin key cards.
- Intelligent decision support software able to fuse all localisation behavioural and disaster escalation data to provide real-time visualisation, passenger counting and evacuation decision support.
- Innovative shore or ship-launched UAV for localising people in the sea in short time and assisting SAR operations when accident occurs in extreme weather, during the night or in a remote location.
- Low-cost lifeboat mounted radars for people localisation in the vicinity of the boat even in extreme weather conditions.

The project intends to deploy this system on large passenger ships provided by RCL and Louis Cruises and verify its compliance with maritime legislations. The involved partners in the Lynceus2Market project are namely:

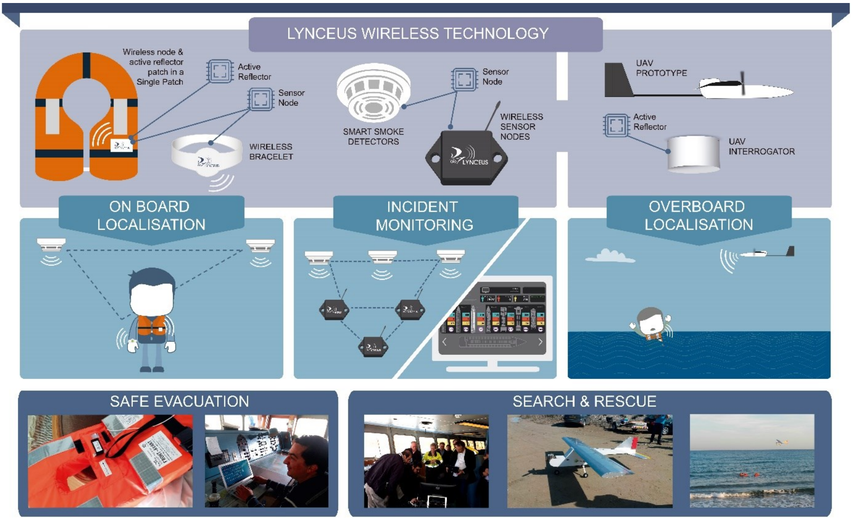

Figure 1-1 Lynceus2Market Technologies [LYN]

TALOS: this partner is specialised in project management and is the coordinator of the project. They are leading the administrative, financial and legal management of the project.
JRCC: Search and rescue (SAR) authority that helps towards the enhancement of the Lynceus2Market overboard localisation system to the overall SAR procedure. JRCC is actively involved in the design of the UAV launching platform and also during the SAR overboard localisation exercises.
Autronica and Safe Marine: Those partners are specialized in the smoke and fire detection sector. AUTRONICA is a leading manufacturer and supplier of fire safety and maritime safety monitoring equipment. It contributes significantly in the design and development of both the on-board technologies as well as towards the system integration and validation via the large-scale demonstrations. Safe Marine is involved in the on-board technologies design and development stage as well as in the disaster escalation related tasks.
G.G. Dedalos: provides necessary know-how for the UAV related technologies that are developed in the project. It is responsible for designing and manufacturing for the UAV and its launching platform.
OPTIONS: is responsible for developing the decision support system. OPTIONS is also the leader for the mustering of the handheld devices task where the counting and identification of passengers on-board are performed.
Canepa & Campi: is responsible for the design and the production of lifejackets for passenger ships that can carry the Lynceus2Market smart modules.

ATEVAL and FMV: as specialised industrial associations, they are involved actively during the demonstration and system validation stage as well as the market replication related tasks.
SignalGeneriX: is the technical manager for the project. This partner is actively involved in the design, development and optimisation of all the hardware and software components.
CSEM: provides essential know-how for the projects low power system-on-chip technology, low power wireless sensor network (WSN) and antennas. CSEM also contributes to the interfacing of the wireless and wired communication media (gateway functionality of smoke detectors) as well as to component integration, validation and testing.
TUD: The chair for circuit design and network theory is responsible for the design of the localisation technologies that helps locating the passengers during emergencies. It also contributes to the decision support system interface design as well as to the components system integration and validation.
MARINEM: with its expertise on the development of shipboard emergency procedures, it provides the knowhow on the way these procedures are applied and implemented. They are leading the project demonstration and system validation.
RCL and LOUIS: are major cruise operators responsible for the large-scale demonstrations. They provide their cruise ships for the demonstration and system validation of the Lynceus2Market system under real-life operational conditions.
Lloyd's Register: is responsible of risk management, system validation, standardisation, dissemination, market replication and exploitation.

1.2. Scope, Objectives and Thesis Outline

The scope of this work is the design of localization systems that can be easily installed and integrated on both cruise ships and SAR vessels in order to locate simultaneously a larger number of passengers, either on-board or overboard the ship, during emergencies. In this work, two localization systems are developed for both overboard and on-board localization. These systems aim at improving the response time for people localization by SAR operations and/or ship crew-members. Moreover, the developed localization systems can be utilized in many other applications that require localization either outdoors or indoors.

Some overboard localization solutions already exist in the market, but they either depend on the global positioning system (GPS) for passenger localization [AIS] or on a Wi-Fi network around the cruise ship where location data are sent in regular bursts [OET, SHS]. The use of the GPS is an expensive solution, and the use of a Wi-Fi network requires the placement of several nodes around the cruise ship. The overboard localization system that will be presented in this thesis aims at providing smart tags that can be easily integrated into lifejackets and localized using either a handheld device or a UAV equipped with an interrogator station. After the smart tags localization is performed, localization data is sent to the command centre of the SAR operations.

As for the on-board localization, FMCW radar systems have been proven to be a good candidate for indoor localization systems with a high precision and accuracy [SSU+12, MOH+10]. However, the accuracy of FMCW radar systems is degraded in indoor environments due to multi-path interferences caused by static or moving scatterers. Therefore, this work aims at providing a novel integrated FMCW radar system based on sub-harmonic generation that is capable of mitigating multi-paths resulting from the direct reflections of the interrogating signal in complex indoor environments like the cruise ships decks and cabins. The design and implementation of the sub-harmonic active reflector tags necessary for the proposed sub-harmonic FMCW radar system is investigated as well.

This thesis is organized as follows: After presenting the motivation and the scope of the work in this chapter, the proposed overboard RSS-based localization system is presented in chapter 2 together with the proposed weighted least-mean-squares (WLMS) algorithm. The design of printed circuit boards (PCB) for both smart tags and interrogator stations is presented and both simulation and measurement results are shown and compared to the state-of-the-art RSS-based localization systems.

In chapter 3, an introduction to FMCW radar systems is given together with the adopted architecture suitable for the scope of the desired application. Possible interferences that affect the accuracy of FMCW radar systems are analysed. Then, a novel FMCW radar system based on sub-harmonic generation is proposed in order to mitigate possible multi-path interferences in indoor environments.

In chapter 4, the circuit design of a 24 GHz frequency divider-by-10 as an active reflector tag is presented together with the simulations and measurements results. The design and measurements of the active reflector tag PCB are also presented.

In chapter 5, the design of a 24 GHz chirp generator is presented together with the design of the radio frequency (RF) front-end PCB for the proposed sub-harmonic FMCW radar system. Simulations and measurement results are presented as well.

In chapter 6, indoor ranging and positioning measurements are performed using the proposed novel integrated sub-harmonic FMCW radar system. The results are analysed and compared to the state-of-the-art FMCW radars.

Finally, in chapter 7, the work of this thesis is concluded and an outlook on future work is provided.