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## Problem description

### Background

Multi-target tracking is a key ingredient in collision avoidance system for autonomous vehicles. Multi-frame tracking methods are commonly acknowledged as gold standards for multi-target tracking. The purpose of this master thesis is to develop a complete multi-frame system for autonomous ships, based on sensor inputs from radar and the Automatic Identification System (AIS).

### Proposed tasks

The following task are proposed for this thesis:

- Extend an integer-linear-programming (ILP) based tracking method with suitable algorithms for track initiation and track management
- Develop a framework for fusion between radar tracks and AIS tracks
- Develop alternatives to N-scan pruning in order to enhance the computational efficiency of the tracking method
- Implement the tracking system in Python and/or C++
- Test the tracking system on simulated data
- Test the tracking system with real data recorded with the Navico 4G broadband radar mounted on Telemetron

### Autosea

This thesis is associated with the AUTOSEA project, which is collaborative research project between NTNU, DNV GL, Kongsberg Maritime and Maritime Robotics, focused on achieving world-leading competence and knowledge in the design and verification of methods and systems for sensor fusion and collision avoidance for ASVs. The project has access to supervision and physical test platforms through our industry partners.

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# Preface

The work presented in this thesis

Erik Liland  
Trondheim, 2017-06-05

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# Abstract

The answer is 42

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# Glossary

**AUTOSEA** A collaborative research and development project between NTNU AMOS and the Norwegian maritime industry with aim to attain world leading knowledge in design and verification of control systems for ASVs.

**COLREGS** Convention on the International Regulations for Preventing Collisions at Sea.

**Radar** Acronym for Radio Detection And Ranging. A device that uses radio waves to measure distance and bearing to other objects.

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# Acronyms

**AIS** Automatic Identification System

**ASV** Autonomous Surface Vessel

**CAS** Collision Avoidance System

**MHT** Multi Hypothesis Tracking

**MUNIN** Maritime Unmanned Navigation through Intelligence in Networks

**TOMHT** Track Oriented Multi Hypothesis Tracker

# Chapter 1

## Introduction

### 1.1 Motivation

Automation- and control technology have throughout the history been a crucial part of reliving humans from for instance dangerous, exhaustive, repetitive or boring work. Examples of this is automation and robotics in production facilities, remotely operated vehicles for working and exploring the deep sea and disarming explosives. The level of self control varies from remotely controlled to self sensing and planning without human interaction.

The early motivation for automation was probably, and in many situations still are, to improve speed, quality and consistency, which all tends to lead to better economics. With a still decreasing threshold for automating processes, more focus is applied on easing the burden on people, either by combining robotics and humans in the same operation, or fully automate the task. These jobs are typically repetitive, dangerous or both.

Although humans are capable of both self improving and easily adapting to new tasks, they will always have good and bad days, performing the same task slightly different or be bored and unfocused. These are all aspects that leads to inconsistency and errors, which may not be a problem in a production environment with quality inspections, though inconvenient, but can be fatal in critical applications.

There also exists several places where humans and automated system work together to exploit both strengths, for instance in aviation where the pilots are always present in the cockpit, but the autopilot are flying the plane most of the time. This gives the pilots freedom from a very static and repetitive task where a human error could have

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fatal consequences. This symbiosis is somewhat similar to the workload on the bridge of commercial vessels, where the autopilot steering the ship most of the time, while the crew is setting the course.

For vessels that do very repetitive routes and jobs, like ferries and short domestic cargo transport, the mental fatigue on the crew can be an issue. Because of the need for crew in emergency situations, customer service and ship maintenance, larger ferries would still need crew. They could however be steered by an automated system, which is never tired, bored, intoxicated or distracted in any other way. This is one of many applications for Autonomous Surface Vessels (ASVs).

The sensor and control system needed for safe automation of any vessel is large and complex, and requires several layers of fault barriers to prevent system errors from spreading and the ability to self monitor its own performance. The control system would know its own position and desired position, it would have access to maps to make a route, a Collision Avoidance System (CAS) to deviate from its planned route to act in accordance with the rules at sea (COLREGS) based on real-time situation information from the sensors on the vessel.

For ASVs to be a viable alternative to human guided ships, the potential savings must be more than marginal, and the control system must be at least as safe as a human operated vessel. The state-of-the-art is not at this point yet, but recent initiatives by large corporations in development in ASVs and the regulation of a dedicated test area for ASVs in Trondheimsfjorden in Norway are just two examples on the direction this technology is headed.

The world's first autonomous ferry might be between Ravnkloa and Vestre kanalkai in Trondheim. The Norwegian University of Science and Technology (NTNU) and Det Norske Veritas Germanischer Lloyd (DNV GL) are working on a collaborate project to develop a small autonomous battery powered passenger and bike-cycle ferry, as an alternative to a bridge over a canal.

An indicator of the momentum autonomous surface vessels have is the Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) project, which is a collaborate project between several European companies and research institutes, partially funded by the European Commission. The project aims at developing and verifying concept of autonomous vessels with remote control from onshore control stations.

This work is focused on the sensor fusion which generates a real time data stream into the control system, enabling situational awareness and the foundation for predictive CAS like [1], which also was a part of the AUTOSEA project.

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## 1.2 Previous work

This work is based on a pre-master project executed autumn 2016 [2]. In this project, it was shown that several off-the-shelf Integer Linear Programming (ILP) solvers was capable of solving the data association optimization problem in a single sensor Track Oriented Multi Hypothesis Tracker (TOMHT). It also showed that under good to moderate conditions, the performance return when increasing multi-scan window more than a relative low threshold, was very low.

## 1.3 Outline of the thesis

Chapter 2 provides an introduction to the sensor systems used in this work, as well as some of the different Multi Hypothesis Tracking (MHT) variants that exist. Chapter 3 presents an overview of the complete measurement-to-guidance system and an in-depth explanation of the fused radar and AIS TOMHT tracking system. Chapter 4 presents the results of simulated scenarios with different level of clutter, and real scenarios recorded with an ASV in Trondheim, Norway. A discussion of the results and evaluation of the performance with respect to safety at sea is presented along with a conclusion in Chapter 5.



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# Chapter 2

## Theoretical Background

### 2.1 Radar

RAdio Detection And Ranging (RADAR) is a detection technology that uses radio waves to observe stationary and moving objects. A transmitter sends out radio waves and a receiver is waiting for reflected echo's from objects. The transmitter and receiver will in many situations be in the same location as the transmitter. Depending on frequency, a radar can observe solid objects like air-crafts, ships, terrain, people, road vehicles and weather formations.

The first implementation of an instrument that were able to detect the presence of distance metallic objects by radio waves was done by Christian Hülsmeyer in 1904. His invention did not measure the distance to objects, but whether there was an object in the direction of the instrument. The radar as we know it today was introduced in the mid to late 1930's, with world war two triggering a research to improve the still immature technology to be used in military applications. After the war, the technology matured and where put in use in several civil applications, where air traffic control, maritime safety and weather monitoring is the most common.

### 2.2 AIS

AIS is.

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## 2.3 Tracking

Tracking, in this context, is to follow stationary and moving targets that are observed by a system without included association data. The problem is to know which measurements belong together over time, often refereed to as the data association problem.

Tracking is a relative new filed of study, originating from the military technology race post 1945, enabled by the development of microprocessors and computers from the 60's. The applications ranged from sonar tracking on both submarines and navy vessels, to air control and missile guidance. This historical background is likely the reason for most published papers using these types of applications as background for testing. In recent years, tracking people and vehicles from visual- and Synthetic Aperture Radar (SAR) imagery have also become a topic in the research community [3]–[5]. There have also been published some research work on usage of tracking for ASVs [6], [7], although both are focused on interaction and response to external events.

There are several factors contributing to the challenge of good tracking; clutter, lower than unity Probability of detection ( $P_D$ ), multiple detections of the same vessel and wakes. Clutter is a term for unwanted measurements or noise, which is inherent in every observation system. For a maritime radar, this can be caused by waves, rain, snow, birds or shore echo. A common assumption on clutter is to assume the amount being Poisson  $P_D$  is a measure of how persistent the target is in the measurements, and will vary much between different types of targets.

### 2.3.1 Single-target Tracking

The simplest approach to tracking is single-target tracking, where it is assumed that there are only one target in the measurement area, and any other measurement is regarded as either extra measurements of the target or false measurements, often referred to as clutter.

### 2.3.2 Multitarget tracking

A subset of tracking is multitarget tracking, where the problem expands to jointly estimate both the number of targets and their trajectories. While a large number of tracking techniques have been developed, the three most used are Joint Probabilistic Data Association Filter (JPDAF), MHT and Random Finite Set (RFS) [8].

JPDAF is a multitarget expansion of Probabilistic Data Association Filter (PDAF) which is a single-target tracking technique. The essence of them both is consider

# Chapter 3

## Implementation

Implementation here.

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# Chapter 4

## Results

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# Chapter 5

## Discussion and conclusion

Discussion and conslusion here.



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