Autonomous Situation Awareness for Navigation
Sammenfatning

ASAN-projektet identificerede som udgangspunkt, at automatisk situations opfattelse (awareness) er en helt grundlæggende teknologi hvis en computer skal yde fornuftig og kompetent beslutningsstøtte til en navigatør, eller når computer algoritmer selv skal kunne give råd om elle træffe beslutninger om sikker navigation.

- ASAN har bidraget til udviklingen af autonom maritim teknologi på helt centrale områder:
  - Objektgenkendelse til søs med brug af kameraer i synlige og infrarøde områder.
  - Metoder til at forstå situationer med forskellige typer af omgivende fartøjer, fortolke vigepligtsreglerne (COLREGS) og forvente hvordan andre fartøjer vil navigere.
- ASAN-resultater er publiceret i videnskabelig sammenhæng:
  - I proceedings fra 7 internationale konferencer, ét er indsendt til tidsskriftet Ocean Engineering.
  - Resultater om objekt detektion med varme følsomt kamera og neurale netværk, opnåede en prestigefuld young author best paper price.
- ASAN-resultater er fremlagt på 8 møder i Danmark, der var målrettet til interessenter i den maritime sfære.
- Alle ASAN-resultater er båret videre og er implementeret i ShippingLab.
- Kolleger i udlandet inviterer jævnligt til samarbejde med begrundelse i at Danmark er foran med situations-analyse og kamera-baseret objekt detektering.
- ASAN har sat markante spor i udviklingen af maritim autonom teknologi.

Støtten fra DDMF, Orients Fond og Lauritzen Fonden har været været uvurderlig for forskning og udviklingen af autonom teknologi i Danmark og vi er meget taknemmelige for den tildelte støtte.

På vegne af projektdeltagerne
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Final Report for ASAN
Autonomous Situation Awareness for Navigation

Project abstract

The ASAN research project addresses a key function in future autonomy solutions, the situation awareness. We conduct research in the area, develop prototypes in collaboration with expert navigators, develop validation scenarios for decision support and test quality attributes from real data collected at ferries in Danish waters.

Navigators use a combination of perception, understanding and anticipation, based on careful outlook. Lack of situation awareness has been a root-cause of several collisions and groundings. The project will develop reliable computer algorithms that can perform all elements of situation awareness. The aim is to reduce risks at sea and be a basis for autonomous navigation. Algorithms will process images from electro-optical sensors, radar and other sensors. They will interpret surroundings and predict behaviours of other traffic. Algorithms will estimate imminent risks and provide decision support for safe manoeuvring.

The project will meet its ambitious goal through collaboration between expert navigators and experienced researchers in marine automation, sensor fusion and intelligent learning. Industry and navigation school participation will help disseminate results, and workshops will target the wider maritime community.

Project outreach

Presentations for stakeholders at

- Fyn's Maritime Forum (Sep 2018),
- DTU High Tech Summit (Nov 2018)
- ISO WG10 meeting in Copenhagen (Sep 2018),
- SIMAC – DFDS meetings regarding decision support, Spring 2019 (meeting series was abrupted by COVID19 lockdown and DFDS restrictions on vessels visits),
- IDA Maritime, Mar 2019,
- DTU CCAS Inauguration Oct 2020
- Digital Technology Summit, Nov 2021, Copenhagen
- Maritime Research Alliance, Dec, 2021.

Public outreach was not possible during the periods of COVID lockdown.

Scientific Publications by ASAN and jointly by ASAN and ShippingLab:

1. Dimitrios Papageorgiou, Mogens Blanke, Marie Lützen, Mette Bennedsen, John Mogensen, Søren Hansen: Parallel Automaton Representation of Marine Crafts' COLREGS Based Manoeuvering Behaviours. CAMS 2019, Daejeon, Korea. IFAC-PapersOnLine. Volume 52, Issue 21, 2019, pp 103-110, doi: 10.1016/j.ifacol.2019.12.291.
   Presents a discrete event methodology (automata theory) to interpret COLREGS given observation of objects in own ship's surroundings.
   https://www.sciencedirect.com/science/article/pii/S2405896319321767?via%3Dihub

2. Frederik E. T. Schöller, Martin K. Plenge-Feidenhans'l, Jonathan D. Stets, Mogens Blanke: Assessing Deep-learning Methods for Object Detection at Sea from LWIR Images. CAMS 2019, Daejeon, Korea. *Received CAMS'2019 Young Author Best Paper Award.* IFAC-PapersOnLine. Volume 52, Issue 21, 2019, Pages 64-71, doi: 10.1016/j.ifacol.2019.12.284.
   Novel results on detectability of other vessels at sea using heat sensitive cameras and neural net-based detection algorithms.
   https://www.sciencedirect.com/science/article/pii/S240589631932169X?via%3Dihub

3. J.D. Stets, F. E. T. Schöller, M. K. Plenge-Feidenhans'l, R. H. Andersen, S. Hansen and M. Blanke: Comparing spectral bands for object detection at sea using Convolutional Neural Networks. ICMASS'2019, Trondheim, Norway. Journal of Physics: Conf. Series 1357 (2019) 012036. doi:10.1088/1742-6596/1357/1/012036.
   New results on utilization of different spectral bands for object detection at sea.
   https://backend.orbit.dtu.dk/ws/portalfiles/portal/198806900/Stets_2019_J._Phys._Conf._Ser._1357_012036.pdf

4. F. E. T. Schöller, M. Blanke, M.K. Plenge-Feidenhans'l, L. Nalpantidis: Vision-based Object Tracking in Marine Environments using Features from Neural Network Detections. IFAC'2020 World Congress, Berlin. IFAC-PapersOnline vol 53(2), 2020. 14517–14523, Doi: 10.1016/j.ifacol.2020.12.1455
   Paper demonstrates camera-based tracking of objects. Enhances detection probability and object classification by ability to track using only vision based information.
   https://orbit.dtu.dk/en/publications/vision-based-object-tracking-in-marine-environments-using-feature

5. P. N. Hansen, D. Papageorgiou, M. Blanke, R. Galeazzi, M. Lützen, J. Mogensen, M. Bennedsen, D. Hansen: COLREGS-based Situation Awareness for Marine Vessels - a Discrete Event Supervision Approach. IFAC'2020 World Congress.
   Showed how COLREGs rules for navigation are assessed as part of situation awareness analysis, and in particular how on. vessels interpret the situation. The latter is a novel contribution to the situation awareness literature.
   https://orbit.dtu.dk/en/publications/colregs-based-situation-awareness-for-marine-vessels-a-discrete-e

6. Frederik E. T. Schöller, Martin K. Plenge-Feidenhans'l, Jonathan D. Stets, Mogens Blanke: Object Detection at Sea Using Ensemble Methods Across Spectral Ranges. CAMS 2021. Science Direct, IFACpapers OnLine. Volume 54, Issue 16, 2021, Pages 1-6,

doi: 10.1016/j.ifacol.2021.10.065
Showed object detection enhancements obtainable by simultaneous use of cameras in different spectral ranges: visible, near infrared and long wave infrared (heat sensitive). Results make definite conclusions in terms of pixel area needed in an image to make object detections with a specified detection probability.
https://backend.orbit.dtu.dk/ws/portalfiles/portal/261942430/1_s2.0_S2405896321014671_main.pdf

7. Kjeld Dittmann, Peter Nicholas Hansen, Dimitrios Papageorgiou, Signe Jensen, Marie Lützen, Mogens Blanke: Autonomous Surface Vessel with Remote Human on the Loop: System Design for STCW Compliance. CAMS'2021. Science Direct, IFACpapers OnLine, 54(16) (2021) pp 224–231 Doi: 10.1016/j.ifacol.2021.10.097
This paper designed an autonomous system, based on the rules of navigators on watch (IMO STCW regulations). The result is an architecture that maps all STCW responsibilities onto the modules of an automation system for autonomy.
https://www.sciencedirect.com/science/article/pii/S2405896321014993?via%3Dihub

8. Dimitrios Papageorgiou, Peter Nicholas Hansen, Kjeld Dittmann, Mogens Blanke: Anticipation of Ship Behaviours in Multi-vessel Scenarios. Submitted to Ocean Engineering, special issue on Autonomous Surface Vessels.
This journal manuscript has two major and novel contributions to autonomous situation awareness. One is the evaluation and projection of a situation based on the interactions of all the vessels in the area of interest. The other is the introduction of a symmetric assessment principle that significantly reduces the complexity of the task.

Links to outreach - videos at conferences during COVID19 lockdown:

Frederik Schöller et al: https://www.youtube.com/watch?v=5oDa9Y1qrHs

Peter Nicholas Hansen et al: https://youtu.be/diObP5uisM8

ASAN research team

The ASAN research had three partners:

- SIMAC (Svendborg Maritime Academy) , Svendborg
- Wärtsila Lyngsø Marine, Hørsholm
- DTU (Lyngby Campus) with DTU Elektro (Automation and Control Group) and DTU Compute

Professor Mogens Blanke from DTU Elektro was Principal Investigator.

Participants from the partners were:

- ***DTU Electrical Engineering:***
  - *Mogens Blanke, Professor (Principal Investigator)*
  - *Søren Hansen, Associate Professor*
  - *Dimitrios Papageorgiou, Dost Doc, until October 2020.*
  - *Peter I. H. Karstensen, Research Assistant, from Sep 2020.*
  - *MSc students were employed to help with software implementation and with annotation for use in machine learning.*

- ***DTU-Compute****:*
  - *Jonathan Dyssel Stets, PhD From DTU Compute, ASAN Post-Doc 50% until June 2020.*

- ***SIMAC:***
  - *Marie Lützen (until Jan 2020), Mette Bennedsen, John Mogensen, Jesper Hansen, Michal Magaard Hansen and Dorte Olbæk Hansen, Associate / Assistant Professors at SIMAC.*

- ***Wärtsila Lyngsø Marine:***
  - *Kjeld Dittmann, CEO.*

Detailed status versus plan

The ASAN research had six work packages.

- Sensors and Hardware
- Perception
- Understanding
- Anticipationion
- Implementation, test and simulation
- Project management and dissemination

The original planned activities are shown below, in column 1.
Column 2 briefly highlights status and the main results obtained.

WP 1: Sensors and Hardware	Status
Hardware selection, verification and installation of sensors necessary for the project.	Platform established following workshops with WLM
• T1.1: Select and purchase relevant sensors and hardware • T1.2: Installation and configuration of sensor interfaces and storage for data collection • T1.3: Conduct measurement campaigns for verification and data collection	• Platform has cameras for visual range, near infrared and thermal, radar, compass, gps, AIS, • Done • 6 measurement campaigns in Svendborgsund and at Limfjorden
• D1.1: Workshop on selections of relevant sensors • D1.2: Workshop with industry about performance of sensors	• Done • Done

WP 2: Perception	Status
Investigate methods for object extraction from the sensors (in work package 1). Objects tracking will also be investigated.	Implemented and reported
• T2.1: Analysis and evaluation of existing methods • T2.2: Fusion of data from different sensors • T2.3: Robust extraction of objects • T2.4: Tracking of objects over time (input to work package 4)	• Segmentation replaced by finding bounding boxes for objects. Simpler and faster. • Camera fusion investigated and implemented • Robust extraction demonstrated on acquired data
• D2.1: Article about sensor fusion of maritime data • D2.2: Article about tracking of ships for situational awareness	• Invited article submitted to International Journal of Control, Automation and Systems • Tracking Algorithm documented in paper (4), Video published at IDA meeting, on YouTube and LinkedIn.

WP 3: Understanding	
Recognize objects in classes relevant for navigation. Associate semantic properties with objects to understand their context, importance and manoeuvering possibilities. Understand environment influence on own vessel's capabilities.	Object detection investigated versus pixel area in images.
● T3.1: Analysis of existing methods for object classification ● T3.2: Establish object division and semantic classification ● T3.3: Implementation and test of algorithms	● Three deep learning methods implemented and compared ● Bounding box method used ● Implemented and successfully tested on recorded data
● D3.1: Article-categorization and semantic mapping for navigation ● D3.2: Article-classification of objects for navigation at sea	● D.3.1 replaced by CAMS'2019 paper on object detection in long-wave infrared spectrum published. Published by IFAC PapersOnline. ● D.3.2 published by Journal of Physics (ICMASS'2019)

WP 4: Anticipation	
Investigates estimation and prediction of behavior of individual objects in the vicinity. Compares with observation over time and characterize objects that deviate from expected behavior (e.g. violated COLREG rules). Develop autonomous decision support for safe navigation.	Anticipated intentions of marine craft depend on the COLREGS rules that apply to a given situation.
● T4.1: Estimation of intentions based on tracking from work package 2 and classification from work package 3. ● T4.2: Development and analysis of prediction on relevant test scenarios ● T4.3: Filtering of information for decision support	● T4.1 Workshops have defined the COLREGS rules for own ship. Implemented as fast prototype (not real time) ● T4.1 Analysis and design of decision support functions. Workshops at SIMAC & DTU, Workshops with DFDS. ● T4.2 Algorithms were developed for COLREGS compliant understanding and anticipation. ● T4.2 Data was logged from the SIMAC Training Simulator from scenarios that are used for educating Master Mariners. ● T4.3 A risk evaluation module has been specified. It is to be implemented and validated against the SIMAC simulated scenarios. ●

• D4.1: Journal article about intelligent prediction of intentions • D4.2: Journal article about presentation and usage of information for decision support	• D.4.1 Interpretation of own ship COLREGS situation and necessary navigation published at IFAC World Congress 2020 - publication (6). • D4.2 Dissemination in form of IDA Maritime (October 2020) and the joint article () by DTU and SIMAC

WP 5: Implementation, test and simulation	
Conducts implementation of algorithms for verification, simulation and testing on real-life data. Design of challenging test scenarios for system verification.	

• T5.1: Analysis and choice of relevant test-scenarios for the other work packages.
• T5.2: Conduct test on marine simulator
• T5.3: Recording of real-life data, test and validation
	• Workshops with SIMAC:
	  ▪ 3 on COLREG representation in a computer algorithm
	  ▪ 1 on ARPA radar aided navigation
	• T5.2 Data logging was made from the SIMAC Training Simulator, where SIMAC Navigation Lecturers had prepared a number of navigation scenarios that are used for educating Master Mariners.
	• T5.3 Real-time object detection and radar processing was tested at sea in June 2020 (Delayed by COVID19 Lockdown).
	• T5.3 Validation of awareness algorithms against SIMAC Training Simulator is to be performed (in preparation)
	• T5.3 Recording of real-life data from June had to be repeated because of equipment break down (LWIR camera and IMU unit). LWIR replacement delivery had an 8 weeks latency.

• D5.1: Article about systematic validation of situation awareness algorithms • D5.2: Article to report novel findings on robustness of situation awareness algorithms	• D5.1 The paper (7) considered the systematic design of autonomy, based on situation awareness and the IMO requirements to watch-keeping. • D5.1 Systematic validation of situation awareness requires full information from camera based perception and full information (sweep) from ship's radar. The camera-based perception was not possible to obtain from the SIMAC simulator during ASAN. Images projected on the simulator screen are artistic sketches of ships, structures and coastlines. These are quite different from objects encountered and photographed at sea by on-

	board cameras. Complete new machine learning would be needed and was considered too high in cost/benefit to pursue in the ASAN project ● D5.2 The article on robustness of situation awareness appeared to need substantiation based on validation in simulator scenarios and at sea using a complete autonomous vessel instrumentation. These activities were far more complex than the ASAN project could support and the article will be considered as a part of the ShippingLab activities.

WP 6: Project management and dissemination	
Management of project and reporting on results.	
● T6.1: Planning and management of project phases ● T6.2: Handling of dissemination and outreach	● Project management made by active participation by the Principal Investigator in all parts of the project ● Weekly coordination included all members of the ASAN team and worked very efficiently, albeit with the limits set by the COVID19 close down in March 2020, when we had to go virtual.
Outreach ● D6.1: Workshops with Danish Shipping, Danish Engineering Society (IDA), Danish Society for Naval Architecture and Marine Engineering Foundation ● D6.2: Articles at international conferences and journals (see also individual work packages)	Presentations at - Fyn's Maritime Forum (Oct 2018), - IDA Maritim (Nov 2018), - DTU High Tech Summit (Dec 2018) - ISO WG10 meeting in Copenhagen (Mar 2019), - SIMAC-DFDS workshops on decision support, 2019 until COVID closedown. - IDA Maritime, October 2020 - DTU CCAS Inauguration, October 2020 - Digital Technology Summit, Nov 2021, Copenhagen - Maritime Research Alliance, December 2021, Copenhagen Articles: please see above