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Kwangil Lee and Ørnulf Jan Rødseth

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Address: Børrestuveien 3
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N-0314 OSLO
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PREFACE

These proceedings contain selected papers from the first International Conference on Maritime Autonomous Surface Ships (ICMASS), held in Busan, Republic of Korea, on November 8th and 9th, 2018. The first day of the conference had ten invited presentations from the international autonomous ship community, while the second day contained parallel sessions on industrial and academic topics respectively. A total of 20 industrial and 16 academic presentations were given. From the presentations, six full manuscripts are presented in these proceedings after peer review by two Korean and Norwegian experts.

ICMASS is an initiative from the International Network for Autonomous Ships (INAS, see http://www.autonomous-ship.org/index.html), an informal coalition of organizations and persons interested in autonomous ship technology. In 2018 it was organized by KAUS – Korea Autonomous Unmanned Ship Forum. The plan is to make this a yearly event in different places around the world. In 2019 it will take place in Trondheim, arranged by SINTEF Ocean AS and NTNU in cooperation with the Norwegian Forum for Autonomous Ships (NFAS).

The organizing committee would like to thank everyone who has helped with review of manuscripts, all those who helped to promote the conference and all authors who have submitted and presented their contributions.

Kwangil Lee & Ørnulf Jan Rødseth

Korea Autonomos and Unmanned Ship Forum

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Contents

MASS TECHNOLOGY DEVELOPMENT BY MEANS OF SHIP HANDLING SIMULATION

Hans-Christoph Burmeister[1], **Ah-Ram Lee**[2], **Johannes Oeffner**[3], **Srikanth Shetty**[4], **Laura Walther**[5]

[1,3,4,5] Fraunhofer Center for Maritime Logistics and Services, Hamburg, Germany

[2] Daewoo Shipbuilding & Marine Engineering Co., Ltd., Seoul, South Korea

[1] Corresponding author e-mail: hans-christoph.burmeister@cml.fraunhofer.de, Tel: +49 40 42878-6131
[2] Corresponding author e-mail: arlee@dsme.co.kr, Tel: +82 2 2129-7312
[3] Corresponding author e-mail: johannes.oeffner@cml.fraunhofer.de, Tel: +49 40 42878- 4379
[4] Corresponding author e-mail: srikanth.shetty@cml.fraunhofer.de, Tel: +49 40 42878- 4778
[5] Corresponding author e-mail: laura.walther@cml.fraunhofer.de, Tel: +49 40 42878- 4641

Abstract

This paper will stress the importance of Ship Handling Simulation (SHS)-based Maritime Autonomous Surface Ship (MASS) prototype development and aligns it with the IMO Guidelines on Software Quality Assurance and Human-centered Design for e-Navigation. This is demonstrated by means of an implemented semi-autonomous ship concept. This concept envisions a periodically unmanned bridge with an advanced autonomous navigation system taking over in the absence of the officer of the watch. Thus, it is equipped with autonomous monitoring, collision avoidance as well as harsh weather applications embedded within an ECDIS environment, that require sufficient integration and testing. Based on a requirement analyses, the need for SHS-based testing is derived and a technical framework (SMARTframe) enabling connection of MASS prototypes with SHS on the basis of a message-oriented middleware is introduced. Finally, an indication is given how this set-up ensures proper MASS testing and developing for technical as well as Human-centered Design development.

Keywords: *MASS, Periodically Unmanned Bridge, Human-centered Design, Ship handling simulation, Message-oriented Middleware*

1. Introduction

Maritime Autonomous Surface Ships (MASS) are on the horizon. MASS cover a variety of vessel concepts from ships with autonomy assisted bridges, periodically unmanned bridge, periodically unmanned ships to continuous unmanned ships [1]. However, it is misleading that MASS take out the human factor of the safety equation, as the majority of MASS concepts still foresee control by humans in-the-loop or on-the-loop either from ashore as well as from onboard. This is also why focusing on the human element still plays an important role in the ongoing IMO Regulatory scoping exercise [2]. A proper way to include the human element in the design process is described by the IMO Guideline on Software Quality Assurance (SQA) and Human-Centered Design (HCD) for e-Navigation [3]. In parallel, Ship-handling simulation (SHS) is a known tool for assessing navigational safety and appropriately incorporating the human factor into development projects according to the World Association for Waterborne Transport Infrastructure PIANC [4]. Thus, enabling and assessing MASS concepts in SHS is key to enable human factor, operational as well as safety assessments to fully exploit MASS potentials. Though, this requires a proper integration of MASS prototypes into SHS.

In 2015, DSME and Fraunhofer CML started to develop a first prototype for a semi-autonomous ship concept consisting of an Autonomous Navigation System (ANS) and a Shore Control Centre (SCC). In the end, this concept displays a periodically unmanned bridge operation [2]. Based on the ANS developed, this paper will elaborate how MASS technology development and human-centred design (HCD) can be supported by SHS elaborating DSME's and Fraunhofer CML's approach.

2. Software Life Cycle and HCD

In accordance with IMO, the generic life-cycle for software development can be described by the five steps [4]:

1. Concept Development,
2. Planning and analysis,
3. Design,
4. Integration and testing and
5. Operation,

with this paper focusing on the middle three. The first step is excluded in this paper, as the stakeholder and user analyses is based on the MUNIN project. Information about MUNIN's approach towards stakeholder involvement and its derived concepts can be found e.g. in [6], [7] or [8]. The second step Planning and analysis does primarily cover user and system requirement derivation with regards to software quality assurance as well as HCD, which was done in this project based on a literature review, specifically [8] and some user interviews. The Design phase includes the software architecture as well as the design solution development and its implementation, which was done by the Fraunhofer CML via the SMARTframe framework within a SHS environment. The fourth step on Testing and usability evaluation is only briefly touched in this paper.

3. Requirements Activity

3.1 Overall goal

The high level goal of the ANS in this context has been defined as being an on board system capable to take over certain nautical tasks and decisions during deep sea voyage from an officer of the watch (OOW) to enable a periodically unmanned bridge or advanced decision support. Overall, autonomy hereby means a system of at least level 7 of the Sheridan scale [9], that "executes automatically [and] then necessarily informs the human" for all four stages of Parasuman's information processing steps [10], specifically in the field of decision and action selection.

3.2 Needs, expectations and requirements

More detailed analyses of stakeholder's needs and basic requirements have been derived from [8], but down-scaled to the case of a periodically unmanned bridge. Thus, the scope of processes was limited down to:

- Conduct weather routing,
- Follow track and
- Avoid collision.

The core regulations and principles to be included in the first processes is hereby the Revised Guidance to the master for avoiding dangerous situations in adverse weather and sea conditions [11] and for its derived mandatory specifications it is referred to Table 1 and Table 2, splitting this process into its strategic and operational level. For the latter process, the baseline is the Convention on the International Regulations for Preventing Collisions at Sea [12], with its mandatory requirements being outlined in Table 3. The execution of the follow track process can in principle already be performed by any modern track keeping system, which is why its detailed specification requirements are not detailed here. Instead, it is referred to e.g. [13].

Additional expectations from the user-side have been identified to be an electronic navigational chart-based graphical user interface with touchscreen accessibility stating the different activities of the autonomous system, to allow for a smooth interaction of OOW with the ANS.

Table 1: HWC Specification Requirements (per trigger)

The Harsh Weather Controller (HWC) must
be capable to 1. receive own ship's meteorological observation data 2. receive own ship's motions in all six degrees of freedom 3. consider own ship's current course and voyage plan in IEC 61174 standard route exchange format [18]
4. monitor current environmental conditions (sea state, wind, current) 5. identify possible threats due to current environmental conditions (e.g. based on the MSC.1/Circ.1228 [11]) 6. initiate actions, i.e. course and/or speed alterations, if threats related to current environmental conditions are identified 7. provide information on weather routing recommendation to Collision Avoidance Controller
offer OOW the possibility to 8. define the threshold where current environmental conditions pose a threat to the ship by taking into account the ships seakeeping characteristics

Table 2: SWR Specification Requirements (per trigger)

The Strategic Weather Routing (SWR) must
be capable to 9. consider meteorological forecasts (GRIB1-Format) relevant for planned voyage 10. consider meteorological forecast updates while underway (automatically)
11. evaluate meteorological forecasts effects on expected Fuel-Oil-Consumption (FOC) 12. identify critical safety areas based on meteorological forecasts 13. respect safety areas in route planning if threats along the planned route of own ship related to upcoming environmental conditions are identified 14. optimize the number and position of waypoints of the route with regards to FOC in deep-sea 15. optimize the speed profile between waypoints with regards to FOC in deep sea 16. provide the optimized route in IEC 61174 standard route exchange format [18]
offer OOW the possibility to 17. set weather routing safety parameters

Table 3: CAC Specification Requirements (per trigger)

The Collision Avoidance Controller (CAC) must
be capable to 18. receive own ship's visibility range 19. receive traffic ships' data 20. receive weather safety checks from HWC
21. monitor objects in vicinity (i.e. ships, other objects) 22. detect an avoidance manoeuvre of the other ship 23. evaluate upcoming development of traffic situation based on CPA, TCPA, BC and TBC 24. identify possible upcoming close quarters situations based on CPA, TCPA, BC and TBC 25. consider COLREG B while navigating in open sea 26. evaluate which collision avoidance rules COLREG Part B apply under the prevailing visibility conditions if the vessel is not in a narrow channel or a traffic separation scheme 27. identify if own ship is give-way or stand-on ship 28. ascertain possible solutions to avoid upcoming close quarters situations in compliance with COLREGs if a danger of collision is identified 29. initiate action according to COLREG R17 to avoid collision if an imminent collision situation arises 30. perform a steady course and speed if the unmanned ship is the stand-on ship 31. transmit the traffic picture to OOW 32. notify OOW if an imminent collision situation arises 33. notify OOW if a close quarters situation is developing 34. notify OOW if an appropriate collision avoidance manoeuvre has been identified 35. notify OOW if the system requires assistance in finding a valid solution to avoid pending collision 36. notify OOW if an avoidance manoeuvre of the other ship is detected 37. notify OOW if other ship does not act according to COLREGs 38. notify the OOW if the other ship has been passed well clear and the close quarters situation has been resolved
offer OOW the possibility to 39. define parameters 40. access information about upcoming close quarters situations and proposed safe deviation routes 41. to define a specific collision avoidance maneuver, besides the one found by the CAC

4. Software design activity

4.1 Prototype

The ANS prototype is comprised of different modules to ensure later scalability and reusability of different elements. Thereby, a principle navigation system (as described in [13]) is augmented by three additional core modules that adapt a layout already proposed in [14] (see also Figure 1):

- A Strategic Weather Routing (SWR) Module, that aims for safe operations by avoiding unfavorable weather conditions
- A Harsh Weather Controller (HWC) Module, that reduces negative impacts of encountered environmental forces, as well as
- A Collision Avoidance Controller (CAC) Module, that ensures sailing in compliance with COLREGs Part B.

Besides their primary focus, all modules are aiming to solve their mission under economic considerations, meaning by reducing voyage length and fuel oil consumption. An important link between those modules is the negotiation part between the HWC and the CAC [14]. While both modules do normally serve different aims, which could result in different decisions, this link ensures, as far as possible, a harmonized solution finding by incorporating the HWC in the CAC where necessary. This has also been identified as one important requirement (requirements number 7 and 20 respectively).

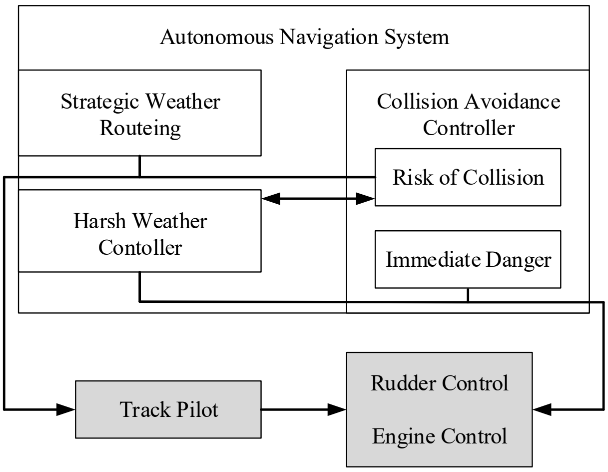

Figure 1. Autonomous Navigation System layout (in dependence on [14]))

4.2 User Interface and interaction

In line with [4], the initial user interface has been designed by a mixture of collaborative design as well as creativity methods including direct involvement of nautical offices, but also experts from software engineering. Hereby, first simulator experiences from the previous MUNIN project have also been taken into account, especially with regards to a better monitoring possibility of the autonomous systems [14].

During the initial design, the principle user interface for the OOW has been defined as an electronically nautical chart with ECDIS like features (e.g. other vessels and monitored route). The main interaction is done via the chart itself, with all main functionalities being touch supported by context menus (see mainframe in Figure 2). Within this standard overview, also the status of all three main components Track Pilot, HWC and CAC is permanently shown as follows (see three squares in the upper left corner of the mainframe in Figure 2):

- Green: Active, normal operation
- Green-flashing: Autonomy-intervention ongoing
- Yellow: Minor incident, user intervention aspired
- Red: Deactivated/can’t fulfil mission; user intervention needed

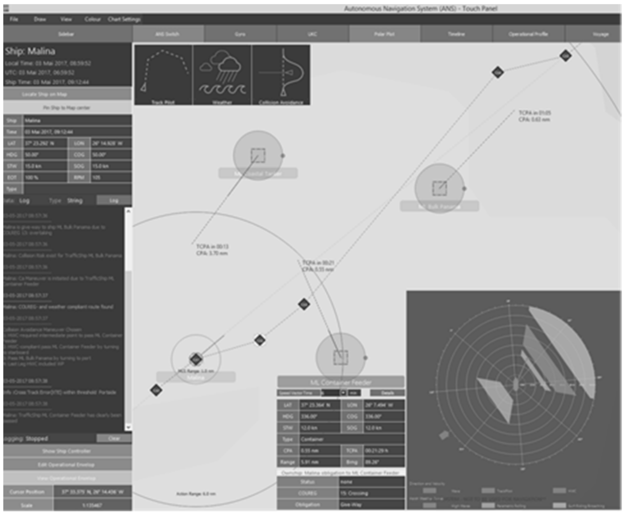

Figure 2. ANS Interface layout

Besides those permanent visible items, a status bar including an ANS log shows the OOW the major own-ship characteristics and informs the OOW about the internal progress and status of the ANS, to fulfil e.g. requirement numbers 32 to 38 (left hand of the mainframe in Figure 2). Further information are purely shown on request on a context basis, like e.g. the data of the traffic ship or the current weather polar plot in the example in Figure 2 (right hand corner on the bottom).

Next to this monitoring interface, the OOW can interact with the ANS by defining its operational envelope, which could be compared to the digital representation of the standing orders. Amongst others, the operational envelope contains the following:

- Monitoring and Action Range: What radius from the vessel shall the ANS monitor and when shall the CAC react;
- Traffic ship handling: which types and to what degree shall traffic ships be respected in the CAC (ignoring, passive monitoring or active evading);
- Ship domains for traffic ships: what are ship-specific safety characteristics with regards to passing distances and preferred sides;
- Maximum cross-track deviation: How far is the ANS allowed to deviate from the original course line;
- HWC vs. CAC priority;

In addition to the standard operational envelope, the OOW can at any time access those values and even make specific exemptions or changes via the touch-screen user interface – before or after the autonomy support. The example in Figure 2 shows e.g. the individual traffic ship domains as circles, which can be directly adjusted by pinch, zoom or pan gestures. The ship-specific adjustment is then taken into account for a rerun of the evasive manoeuvre being determined by the CAC. In a similar way, the OOW can also directly change the CAC's output for the proposed evasive manoeuvre, by e.g. just panning the waypoint to another, preferred position (e.g. for requirement number 41).

4.3 Test-bed

As the proposed prototype as well as its operation is rather complex, a specific test-bed is designed to allow for proper ANS experience, developing as well as user testing. However, as equipping a real vessel directly with a test system is expensive as well as challenging from a legal and liability perspective, an alternative is needed. For harbour channel design studies, which by nature do exclude the use of a real vessel for testing as well, it is e.g. common sense, that nautical experts participating in a SHS exercises is "the only way to ensure that technical ship handling and the important human factors, are sufficiently incorporated" [5]. Thus, incorporating the ANS into a SHS environment is aimed for enabling proper human testing.

4.4 Software Architecture

Modularity, centralisation, scalability, reusability and maintainability are key features for rapid but sustainable software development. With SMARTframe, a specific testbed framework for MASS exists offering high performance in this categories [14]. SMARTframe allows customizing a modular testbed with centralized data exchange unit to fulfil specific user requirements, conceptualizing and developing innovative software solution, integrating simulators, applications or devices into existing testbeds, as well as assessing and validating applications or devices by integrating it into an SHS environment.

Even though the ANS primarily being in an initial prototype development and testing phase, early consideration of reusability and scalability for an efficient development process is aspired. Using SMART-frame's electronic navigational chart application, which is based on a standard ENC Kernel that represent the base chart for ECDIS systems, as the backbone of the ANS development enables easy reusability as well as facilitating possible future certification in this early design phase. Furthermore, SMARTframe also covers standard shipborne interfaces like NMEA or AIS to allow for integration into commercial systems. However, the core of SMARTframe is its Message-Oriented Middleware making it highly modular and scalable, as it allows for a quick implementation of pure data-driven test-beds. [14]

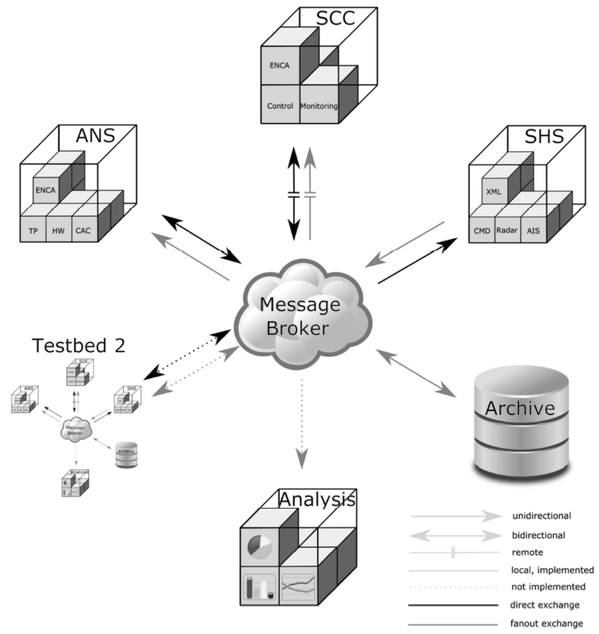

Figure 3. ANS SHS Test-bed sketch (according to [16])

As depicted in Figure 3, a central message broker enables interaction between the SHS, the individual prototypes but also its individual modules. Within SMARTframe, the Advanced Message Queuing Protocol (AMQP) is used, which is an open standard for an interoperable enterprise-scale asynchronous messaging protocol [16]. The concrete broker in this case is RabbitMQ. For details, it is referred to [15]. Thus, the data-driven AMQP design facilitates modular design and enables reusability.

5. Software testing activity

The integration of the implemented ANS prototype took place at a RDE ANS 6000 SHS at Fraunhofer CML as well as at DSME with the SHS of a Korean brand. Concerning the ANS itself, a detailed test against all specification requirements laid out in Table 1 to Table 3 based on pre-defined acceptance criteria as well as by several pre-defined voyage scenarios has been conducted in both environments. Regarding the initial ambition of developing a first operational prototype as demonstrator and test equipment within a SHS environment, the software has been considered reasonable satisfying after several iterations and tests in the SHS fulfilling all pre-defined criteria. Moreover, the ANS technical integration capability could even be tested in 'read-only' mode on board in May 2018 during a six day voyage of the MS HANNAH SCHULTE in the Mediterranean. The easy integration again "demonstrated the capability of the [SMARTframe] to switch from simulated to real-time environment" [15], being also a good indicator for fulfilling the aspired reusability criteria of the IMO Software Guideline [4].

Figure 4. Onboard installation ANS on HANNAH SCHULTE

6. Conclusion

This paper has presented the development process of a periodically unmanned bridge system by DSME and Fraunhofer CML. Thereby, it has highlighted the need for proper user testing methods, like e.g. in a SHS environment, to follow IMO Guidelines requirements and to ensure that user needs and safety is met [4]. Furthermore, the SMARTframe framework for ensuring scalability has been introduced and used during the ANS development. Even so ANS is currently only focusing on a prototype and demonstrator output, SMARTframe ensures software reusability for the next development phases.

According to [3], this next phase would specifically include more detailed user testing including user observation and thinking aloud techniques within the SHS environment to finalize the HCD efforts started and to come up with a periodically unmanned bridge improving ship efficiency and safety in parallel. Besides this concrete case, further MASS technology development by means of SHS testing is even generally aspired as it goes in line with [2] by ensuring that,

- MASS developments are user-driven,
- Safety is not reduced,
- Operability of MASS can be evaluated and
- Human element aspects for MASS are appropriately considered.

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