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ECAMARIS

Enablers and Concepts for Automated Maritime Solutions

Electronic Lookout Technical Requirements

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beyond the obvious

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Summary

The overall goal of ECAMARIS (Enablers and Concepts for Automated Maritime Solutions) project is to create enablers for autonomous solutions providing added value to maritime industry. ECAMARIS focuses on autonomous ship technologies and concepts which serve as enablers for three use cases with estimated business and safety benefits to shipowners: relocation of ship bridge, conditionally and periodically less-manned bridge, and conditionally and periodically unmanned bridge. Conditionally and periodically less-manned or unmanned bridge solutions reduce navigation related operating expenses via more efficient crew utilization and the reduction in the number of crew through an enhanced watch systems.

For supporting the development of the project use cases and the commercialization of their key technologies, ECAMARIS aims to demonstrate that the studied technologies fulfil the existing regulatory requirement of automated ships, being capable of at least the level of safety of conventional ships. This is done by defining minimum technical and functional requirements for the digital line of sight, electronic lookout and conditionally unmanned bridge technology. These requirements are provided by using processes, test methods and research infrastructure developed in the project.
This report lists requirements for the electronic lookout, which were collected from various sources and supported by the shore-based field measurements conducted in real-world conditions in the Harmaja pilot station from February 24th to March 23rd 2023. This report supports the process starting at IMO MSC 104, during which the European Commission plans to propose to put the electronic lookout on the IMO agenda.

Confidentiality	VTT Public

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Preface

This research report lists requirements for the electronic lookout, which is a deliverable for the tasks 2.2.1 and 2.2.2 of the ECAMARIS –project (Enablers and Concepts for Automated Maritime Solutions). These requirements were collected from various sources and supported by the shore-based field measurements conducted in real-world conditions in the Harmaja pilot station from February 24th to March 23rd 2023. VTT developed a test platform featuring a selected camera setup, whose video stream was analysed with a real-time object detector based on YOLO. Two different, pre-trained models were used, other being standard, out-of-the-box model and other custom neural network model especially trained for detecting vessels.

The project steering group consisted of the partners of the Co-innovation joint action (ABB Ltd., AILiveSim Oy, GIM Robotics Oy, Aalto University, Finnpilot Pilotage Oy and VTT). Authors extend their deepest gratitude to steering group for their invaluable support and insightful comments throughout the duration of this task. Their contributions have been instrumental in the successful realization of our goals.

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1. Introduction

Autonomous technology is expected to be a game-changer also in the maritime industry. It is promiseing safer, cleaner, and more efficient maritime operations, as well as creating new business models and opportunities. It also provides a path to solving many of the key challenges facing the maritime industry today, such as insufficient availability of crew to meet the industry's needs.

Using machine vision, machine learning, and AI, the electronic lookout system can expand the situational awareness and improve various detection functionalities, possibly complementing the human lookout role in maritime operations.

However, at present, there is no established methodology to determine technical requirements for autonomous maritime systems, nor for electronic lookout systems in maritime environment. To fill this gap, this task aims to determine a straightforward approach for specifying minimum technical and functional requirements for autonomous maritime applications in general, and particularly for electronic lookout. This task utilizes the electronic lookout requirements specified by Tervo & Lehtovaara [1] describing and suggesting the minimum technical requirements for the electronic lookout as the initial requirement set, supported by trials conducted under clear weather conditions.

This document is constructed as follows. At first, background and requirements for a human lookout are introduced. After this, the actual requirements are listed, divided in sections for operational envelope [2], video system, communication network, detection, camera and its lens, and self-diagnostics. Finally, there are few words about the real-life tests and their results with summarizing remarks.

Abbreviations

8K	Image resolution with a width of approximately 8000 pixels.
AI	Artificial intelligence is the intelligence of machines or software.
BV	Bureau Veritas
CMOS	Complementary metal–oxide–semiconductor is a type of metal–oxide–semiconductor field-effect transistor fabrication process.
COLREG	IMO Convention on the international regulations for preventing collisions at sea.
FF	Full-frame, a 35 mm image sensor format (36 mm × 24 mm)
FOV	Field of View
GAN	Generative Adversial Network
GT	Gross Tonnage
H.264	H.264 is a video compression standard based on block-oriented, motion-compensated coding.
H.265	H.265 is a video compression standard designed as part of the MPEG-H project as a successor to the widely used coding H.264.
HDR	High Dynamic Range
HFov	Horizontal field of view
HW	Hardware
IMO	International Maritime Organisation
IP	Internet Protocol
ISO OSI	The Open Systems Interconnection model is a conceptual model, which provides a common basis for the coordination of standards development for

	the purpose of systems interconnection, from the International Organization for Standardization.
JPEG	Joint Photographics Expert Group, image file type
LAN	A local area network is a computer network that interconnects computers within a limited area such as a residence, school, laboratory, university campus or office building.
MJPEG	Motion JPEG (M-JPEG or MJPEG) is a video compression format in which each video frame or interlaced field of a digital video sequence is compressed separately as a JPEG image.
MMSI	A Maritime Mobile Service Identity is effectively a maritime object's international maritime telephone number, a temporarily assigned UID, issued by that object's current flag state.
MPEG4	MPEG4 is a group of international standards for the compression of digital audio and visual data, multimedia systems, and file storage formats.
MTF	Modulation Transfer Function describes the optical performance of a lens or objective.
ODD	Operational Design Domain essentially defines the operating environment for which a system is designed for.
OoS	Out of sight
OOW	Officer of the watch is a term used in the maritime industry to refer to the officer on the bridge, who is responsible for the safe navigation and operation of the vessel.
PDAF	Phase-detection Autofocus
ppm	Parts/packets per million, the number of units per million units.
RCS	Radar Cross Section
RTP	Real-time Transport Protocol
RTSP	The Real Time Streaming Protocol is an application-level network protocol designed for multiplexing and packetizing multimedia transport streams (such as interactive media, video and audio) over a suitable transport protocol.
SoA	State of the Art
SOLAS	SOLAS Convention, the International Convention for the Safety of Life at Sea.
STCW	IMO International convention on standards of training, certification and watchkeeping for seafarers.
TCP	Transmission Control Protocol is a communications standard that enables application programs and computing devices to exchange messages over a network.
UDP	The User Datagram Protocol is a communication protocol used across the Internet for especially time-sensitive transmissions such as video playback.
UID	A unique identifier is an identifier that is guaranteed to be unique among all identifiers in communication network used for those objects and for a specific purpose.
YOLO	A state-of-the-art, real-time object detection system that is a part of the field of computer vision and artificial intelligence.

Lookout and electronic lookout

A lookout is a task conducted at the vessel's bridge to maintain a continuous watch of various objects that can impact the navigation task, and cause harm to the vessel. More precisely STCW [3], the

COLREGS [4] and IMO [5] have formed lookout requirements for vessels and watchkeeping practices for all merchant ships. These can be summarized as follows:
Every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision, stranding and other hazards to navigation [4].
According to STCW:
“A proper look-out shall be maintained at all times in compliance with the previous and shall serve the purpose of:

1. maintaining a continuous state of vigilance by sight, hearing, and all other available means regarding any significant change in the operating environment;
2. fully appraising the situation and the risk of collision, stranding and other dangers to navigation; and
3. detecting ships or aircraft in distress, shipwrecked persons, wrecks, debris and other hazards to safe navigation.” [3]

IMO forms principles for the lookout as follows:
“Every ship shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision, stranding and other hazards to navigation. Additionally, the duties of the look-out shall include the detection of ships or aircraft in distress, shipwrecked persons, wrecks and debris. In applying these principles the following shall be observed:

1. whoever is keeping a look-out must be able to give full attention to that task and no duties shall be assigned or undertaken which would interfere with the keeping of a proper lookout;
2. the duties of the person on look-out and helmsman are separate and the helmsman should not be considered the person on look-out while steering; except in small vessels where an unobstructed all round view is provided at the steering position and there is no impairment of night vision or other impediment to the keeping of a proper look-out;
3. there may be circumstances in which the officer of the watch can safely be the sole lookout in daylight. However, this practice shall only be followed after the situation has been carefully assessed on each occasion and it has been established without doubt that it is safe to do so. Full account shall be taken of all relevant factors including but not limited to the state of weather, conditions of visibility, traffic density, proximity of navigational hazards and if navigating in or near a traffic separation scheme.” [5]

Using machine vision, machine learning, and AI, the electronic lookout system can expand the situational awareness and improve detection, possibly complementing the human lookout role in maritime operations. Electronic lookout is a technology application that can replace a human lookout, e.g., to enable a conditionally and periodically less-manned bridge at least under some environmental conditions. A digital line of sight is a necessary but not a sufficient condition for an electronic lookout. The introduction of an electronic lookout may also enable new onboard work routines to improve seafarers’ wellbeing and reduce fatigue, and thus lower the probability of occupational accidents and ship collisions and groundings.
The electronic lookout system in this requirements document concerns only visible cameras. Document lists requirements needed for the detection phase depicted in Figure 1. i.e., detecting that there is something else than water.

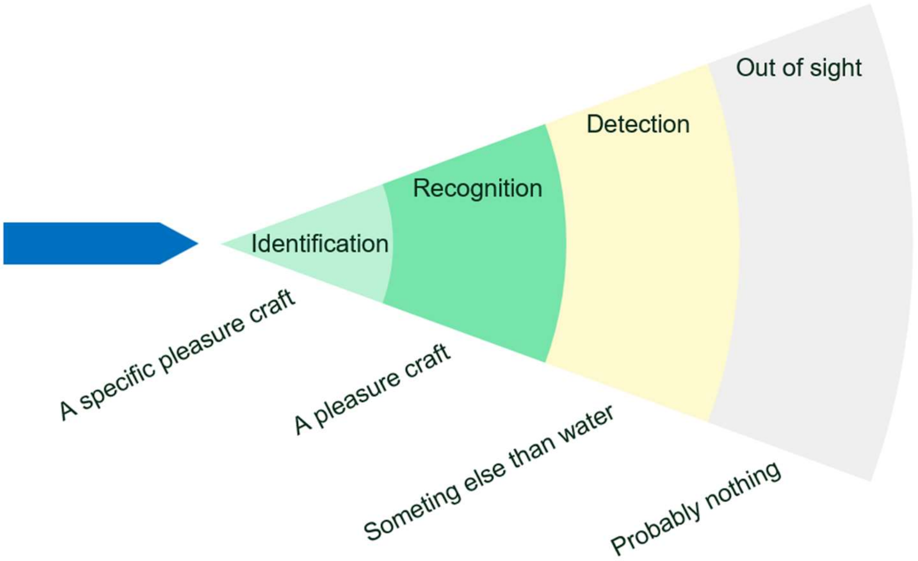


Figure 1 Definitions for the Identification, Recognition, Detection and OoS (adapted from K. Tervo)

2. Requirements for electronic lookout

The following lists requirements for electronic lookout. In some level this can be understood as a video surveillance system for marine applications. Challenge here is that testing of cameras, lenses and fused systems is not standardised, and casually collected information reveals that camera and system suppliers do not fully understand the limitations of their products. Collecting all relevant requirements into a single table was a more tedious task than its name indicates. The camera system analysed in the following chapters is an imaginary one, intended to be used in merchant, cargo, or passenger ships. These requirements are divided into following groups: Operational envelope [2], Video system, Network, Detection, Camera and its lens, and Self-diagnostics. The table below lists requirements, reasoning for the requirement, reference / regulation / guideline, and priority level (mandatory or optional). This list is not supposed to be a complete set of requirements but provides an appropriate list of features to be checked when designing such a system for this application area.

Table 1 Requirements specifying environment and conditions where and when electronic lookout is used, i.e. defining operational envelope of the electronic lookout.

Operational envelope				
	Requirement	**Description / Reasoning**	**Regu. / Ref.**	**Prio. M/O**
EL1	System shall work in open sea environment.	Operational environment limited to open sea circumstances to reduce complexity of the functionalities investigated.		M

EL2	Installation site	Merchant ship, i.e. cargo ship or passenger ship.		M
EL3	The system must work in Beaufort scale 0, 1, 2 and 3.	Beaufort scale = wind speed (m/s) Beaufort 0 = < 0.5 m/s Beaufort 1 = 0.5 – 1.5 m/s Beaufort 2 = 1.6 – 3.3 m/s Beaufort 3 = 3.4 – 5.5 m/s	National Weather Service Observing Handbook No. 1 Marine Surface Weather Observations, 2010, Code for Wind Speed –table, page 2-23. [6]	M
EL4	The sensor shall work under environmental influences normally experienced outdoors when fully exposed to the weather.	"Environmental class IV – Outdoor – General. National requirements apply." For Denmark, Finland, Norway, Sweden, Canada and Russia: "Temperatures may be expected to vary between -40 °C and +60 °C with average relative humidity of approximately 75 % non-condensing. For 30 days per year relative humidity can be expected to vary between 85 % and 95 % non-condensing." For other countries: "Temperatures vary in general between –25 °C and +60 °C / +55 °C including a sunshield with average relative humidity of approximately 75 % non-condensing. For 30 days per year relative humidity can be expected to vary between 85 % and 95 % non-condensing." [8]	IEC 62676-1-1, 2013 [7] SFS-EN 62676-4 [8]	M
EL5	Lighting requirement: above 400 lx	Enough lighting is required for the visible light cameras to capture the view clearly enough to computer-based object detection to work reliably. Sunset and sunrise, Civil twilight: ~400 lx. [9]	Civil twilight - AMS Glossary [9]	M
EL6	The camera shall meet the requirements of IEC 60068 when applicable to marine environment and circumstances.	IEC 60068-2-1, IEC 60068-2-2, IEC 60068-2-6, IEC 60068-2-14, IEC 60068-2-27, IEC 60068-2-47, IEC 60068-2-78	IEC 60068-2-1, 2007 [10] IEC 60068-2-2, 2007 [11] IEC 60068-2-6, 2007 [12] IEC 60068-2-14, 2023 [13] IEC 60068-2-27, 2008 [14] IEC 60068-2-47, 2005 [15] IEC 60068-2-78, 2012 [16]	M
EL7	Sensor enclosure must have ingress	Sensor and its enclosure must endure adverse weather conditions at the sea, as	IEC 60529, 2013 [17]	M

	protection rating IP67.	well as possible water splashes and temporary immersion in water.		
EL8	Nitrogen filled sensor housing.	Required to prevent fogging of the camera housing window.		O
EL9	Lens wiper.	Window in the housing must be kept clean for the camera to be able to provide clear images of the view. A GAN-based solution for water droplet removal, a special algorithm improving camera image quality can also be considered. [18]	Sophonpattanakit, J., 2022 [18]	O

Table 2 Video system requirements.

Video system				
	Requirement	**Description / Reasoning**	**Regu. / Ref.**	**Prio. M/O**
EL10	Timestamping video	There needs to be an indication of the recording time (for archival purposes) Either on screen or as metadata.	STANAG 4609, 2009 [19]	M
EL11	Minimum frames per second for the video stream is 25 fps.	Video stream needs to be updated frequently enough so that there is time to react, and decisions are not based on old data. “Video transport requires real-time behaviour, provided in IP networks by the Real Time Protocols (RTP). RTP provides support for re-ordering, dejittering and media synchronization. All media streams transferred by the RTP protocol shall conform to RFC 3550, RFC 3551, RFC 3984, RFC 3016 and JPEG over RTP according to IEC 62676-2 series.” [20]: Clause 7	IEC 62676-1-2, 2013 [20] STANAG 4609, 2009 [19]	M
EL12	The system will use efficient and standardized codec for video compression.	Using standardized codec will ensure that the collected video can be used easily later/elsewhere. Practically, video codec H.264 or H.265“The methods of storage and/or transmission for video, audio and metadata shall use standard formats, codec’s and containers. The data shall comply strictly with the standards and contain the full information required to decode the content.” [7]: Clause 6.1.3.6	IEC 62676-1-1, 2013 [7] STANAG 4609, 2009 [19]	M

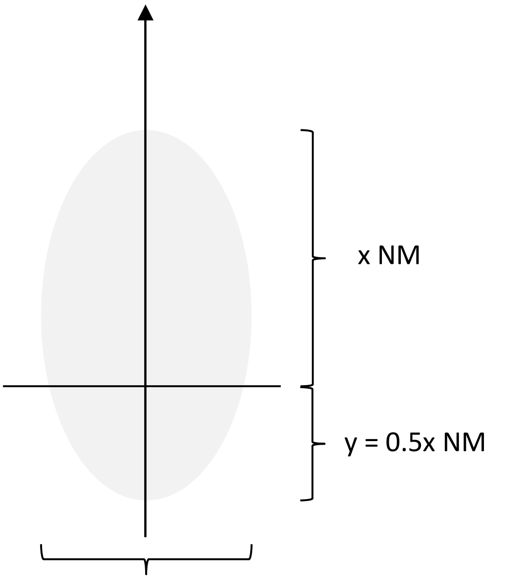
Table 3 Requirements for network and communication.

Network				
	Requirement	**Description / Reasoning**	**Regu. / Ref.**	**Prio. M/O**
EL13	Video latency < 400 ms (one-way)	From IEC 62676-1-2:2013 [20], Table 5: "Maximum one-way latency live stream (incl. encoding, networking, decoding, display): 400 ms for level S2 system; 200 ms for S3; 100 ms for S4." "'The travel time through the pipe' – how long it takes for a packet to travel through the network. -- Maximum latency shall be according to performance requirements of IEC 62676-1-2:2013 [20], Clause 5." [8]: Clause 8.4	IEC EN62676-4, 2015 [8] IEC 62676-1-1, 2013 [7] IEC 62676-1-2, 2013 [20]	M
EL14	Maximum packet loss < 120 ppm	From IEC 62676-1-2:2013 [20], Table 5: Maximum loss: 120 ppm for level S2 system; 60 ppm for S3; 30 ppm for S4. "Packet loss: "The leak in the stream". Packets can get lost because of collisions on the LAN, overloaded network links, or for many other reasons. Loss of packets beyond a very small percentage will degrade video quality. Note that IP video stream uses the User Datagram Protocol (UDP), which, unlike TCP used in non-streaming applications, does not provide the retransmission of packets. Maximum packet loss shall be in accordance with the performance requirements of IEC 62676-1-2:2013, Clause 5." [8]	IEC62676-1-2, 2013 [20] IEC 62676-4:2014 [8]	M
EL15	Jitter or delay variation < 80 ms	From IEC 62676-1-2:2013 [20], Table 6: Maximum peak-to-peak packet jitter: 160 ms for level M1, 80 ms for level M2, 40 ms for level M3, 20 ms for level M4. "Jitter or delay variation: "The received flow variation or pumping of stream" – the continuity with which packets arrive at their destination. Jitter buffers can temporarily delay incoming packets to	IEC62676-1-2, 2013 [20] IEC 62676-4:2014 [8]	M

		compensate the jitter, but only some of the delay variations. These buffers have limits and excessive buffering can result in additional latency. Maximum jitter shall be in accordance with the performance requirements of IEC 62676-1-2:2013 [20], Clause 5." [8]		
EL16	TCP/IP and UDP	"For basic interoperability the IP video devices should be compatible to the protocol requirements of IEC 62676-2-1 in terms of IP connectivity based on TCP/IP and UDP, video stream transport via RTP, MPEG4 or H.264 and stream control based on RTSP." [8]	IEC 62676-4, 2014 [8]	M
EL17	Standardized audio/video transfer protocol over IP.	Software structure of network socket, ISO OSI layer architecture on session layer (5).		M
EL18	Minimum bandwidth for network streaming video is 3000 KBps.	Minimum bandwidth should be 3000 KBps. [21]: 3.5.4, Table 1	BV Guidance Note NI 641 DT R01 E, 2019 [21]	M

Table 4 Specifying requirements for the detection region and distance, as well as detection performance.

Detection				
	Requirement	**Description / Reasoning**	**Regu. / Ref.**	**Prio. M/O**
EL19	Minimum field of view (FOV) is 120 degrees forward.	Required FOV covers the view ahead of the vessel, thus any objects in that direction are prioritized. Objects appearing behind the vessel are ignored. For 360° coverage multiple set of such cameras can be used. "The helmsman's field of vision from the workstation for manual steering should extend over an arc from dead ahead to at least 60° on each side." [22]	ISO 8468, 2007 [22]	M
EL20	System shall detect each object of interest 80 % of the time (true positives).	True positive meaning a correct detection, i.e. detecting an object that is truly present in a frame. "- an indication of the target in at least 8 out of 10 scans or equivalent; " [23]: 5.3.1.1 Equivalent here being the presence of an object in a frame.	MSC.192, 2004 [23]	M

EL21	System shall be able to detect multiple objects within the detection range.	Meaning, even though there are multiple objects in the detection range, all of them shall be detected with the same performance level as indicated in EL20.		M
	Values in requirements from EL22 to EL30 are calculated based on the picture on the right (Figure 2).	 *Figure 2 Ellipse covering the detection region surrounding the vessel with varying distances according to direction. Vessel is located at the origo in the graph.*		M
EL22	Shoreline height above sea level <60 m, minimum detection distance is 20 NM forward.	20 NM – 37.0 km (from [23]: Table 2) Distances depicted in ellipse (Figure 2) for this requirement: x = 20 NM, y = 10 NM, z = 15 NM	MSC.192, 2004 [23]	M
EL23	Shoreline height above sea level <6 m,minimum detection distance is 8 NM forward.	8 NM – 14.8 km (from [23]: Table 2) Distances depicted in ellipse (Figure 2) for this requirement: x = 8 NM, y = 4 NM, z = 6 NM	MSC.192, 2004 [23]	M
EL24	Shoreline height above sea level <3 m,minimum detection distance is 6 NM forward.	6 NM – 11.1 km (from [23]: Table 2) Distances depicted in ellipse (Figure 2) for this requirement: x = 6 NM, y = 3 NM, z = 4.5 NM	MSC.192, 2004 [23]	M
EL25	SOLAS ships with >5 000 gross tonnage (GT) & minimum height of	11 NM – 20.4 km (from [23]: Table 2) Distances depicted in ellipse (Figure 2) for this requirement: x = 11 NM, y = 5.5 NM, z = 8.25 NM	MSC.192, 2004 [23]	M

	10 m, minimum detection distance is 11 NM forward.			
EL26	SOLAS ships with >500 gross tonnage (GT) & minimum height of 5 m,minimum detection distance is 8 NM forward.	8 NM – 14.8 km (from [23], Table 2) Distances depicted in ellipse (Figure 2) for this requirement: x = 8 NM, y = 4 NM, z = 6 NM	MSC.192, 2004 [23]	M
EL27	Minimum detection distance of a small vessel with minimum height of 4 m, is 5 NM forward.	5 NM – 9.3 km (from [23], Table 2) Distances depicted in ellipse (Figure 2) for this requirement: x = 5 NM, y = 2.5 NM, z = 3.75 NM Small vessel with radar reflector meeting IMO revised performance standards for radar reflectors (resolution MSC.164(78)) Radar Cross Section (RCS) 7.5 m^2 for X-Band, 0.5 m^2 for S-Band.	MSC.192, 2004 [23]	M
EL28	Minimum detection distance of typical navigation buoy with minimum height of 3.5 m, is 4.6 NM forward.	4.6 NM – 8.5 km Distances depicted in ellipse (Figure 2) for this requirement: x = 4.6 NM, y = 2.3 NM, z = 3.45 NM "The typical navigation buoy is taken as 5.0 m^2 for X-Band and 0.5 m^2 for S-Band; for typical channel markers, with an RCS of 1.0 m^2 (X-band) and 0.1 m^2 (S-band) and height of 1 meter, a detection range of 2.0 and 1.0 NM respectively." [23]	MSC.192, 2004 [23]	O
EL29	Minimum detection distance of a 10-meter-long vessel with minimum height of 2 m is 3.4 NM forward.	3.4 NM – 6.3 km (from [23]: Table 2) Distances depicted in ellipse (Figure 2) for this requirement: x = 3.4 NM, y = 1.7 NM, z = 2.55 NM Small vessel of length 10 m with no radar Reflector RCS for 10 m small vessel taken as 2.5 m^2 for radar X-Band and 1.4 m^2 for radar S-Band	MSC.192, 2004 [23]	M
EL30	Minimum detection distance of a channel marker with minimum height of 1 m is 2.0 NM forward.	2.0 NM – 3.7 km Distances depicted in ellipse (Figure 2) for this requirement: x = 2.0 NM, y = 1.0 NM, z = 1.5 NM The typical navigation buoy is taken as 5.0 m2 for X-Band and 0.5 m^2 for S-Band; for typical channel markers, with an RCS of 1.0 m^2 (X-band) and 0.1 m^2 (S-band) and height	IEC 62388, 2007 [24]	O

		of 1 metre, a detection range of 2.0 and 1.0 NM respectively. ([24]: Table 2)		

Table 5 Requirements for the hardware of camera system.

Camera and its lens				
	Requirement	**Description / Reasoning**	**Regu. / Ref.**	**Prio. M/O**
EL31	Color camera	Most SoA detection models are trained with color images. Additionally, color includes information that is necessary for navigation (e.g. different colored lights).		M
EL32	High Dynamic Range technique is in use in camera.	Techniques that allow to increase the dynamic range of videos. Other synonyms are: wide dynamic range, extended dynamic range, expanded dynamic range. On chip, or HW HDR is preferred.		O
EL33	Minimum resolution of the camera is 5 Mpx.	Less than 5 Mpx camera will not provide clear enough images for detecting vessels at a distance specified in visibility requirement.	Based on VTT tests done on data collected in Harmaja during spring 2023.	M
EL34	Minimum of 70 pixels per horizontal degree.	Based on VTT tests done on data collected in Harmaja during spring 2023, using specifically trained custom model for detecting vessels. The requirement can be met with appropriate lens system (e.g. zooming) or with high-resolution (8K) cameras.	Based on VTT tests done on data collected in Harmaja during spring 2023.	M
EL35	Minimum diagonal dimension of camera sensor is 9 mm.	Larger sensors typically have larger individual pixels, which means they can capture more light, i.e. better low-light performance, lower noise, and increased dynamic range. Increased noise may have negative affect to detection.	Based on VTT tests done on data collected in Harmaja during spring 2023.	M
EL36	Contrast of the lens shall be at good level for the center and mid-frame.	Contrast of the lens should be determined by calculating the Modulation Transfer Function (MTF) based on images taken from appropriately illuminated ISO test charts: Resolution and Spatial Frequency ISO 12233:2017.		O
EL37	Resolution of the lens shall be at good level for the center and mid-frame.	Resolution of the lens should be determined by calculating the Modulation Transfer Function (MTF) based on images taken from appropriately illuminated ISO test charts: Resolution and Spatial Frequency ISO 12233:2017.	CATAPULT, Performance Testing for Sensors in Connected and Autonomous Vehicles:	O

		”The ability of a camera to spatial resolve an object is defined by the resolution limit of the optics, the detector and the electronics in combination. The diffraction limit or theoretical maximum resolution may be calculated directly from knowledge of the individual system components i.e. lens and detector. However real systems are non-ideal, and functional resolution should be determined by imaging appropriately illuminated ISO test charts: Geometric ISO 17850:2015, Resolution and Spatial Frequency ISO 12233:2017, and calculating the Modulation Transfer Function. Most resolution metrics are designed for grey-scale systems and colour has not been well integrated. Moreover, resolution does not account for other factors such as responsivity and atmospheric transmittance, which need to be considered in when trying to determine the accurate detection of targets.” [25]	CATAPULT Feasibility Study, 2020 [25]	
EL38	Camera shall automatically focus in less than 1 s.	Especially after zooming or panning there should be only small delay when the camera is back in focus so that no vessels go undetected. Phase-detection autofocus (PDAF) or some other more developed method is preferred.	VTT tests done in Harmaja 2023.	M

Table 6 Self-diagnostics requirements defining how the system functions in case of a failure or problem.

Self-diagnostics				
	Requirement	**Description / Reasoning**	**Regu. / Ref.**	**Prio. M/O**
EL39	The system shall have self-diagnostics capability.	The e-lookout system shall be able to assess its performance, and provide this information to the officer of the watch (OOW) for them to determine operational status of the system and whether it has failed or is functioning sub-optimally. For example, in case of light heavily reflecting from the sea surface, saturating the camera image. “Camera: In the case of cameras, the dynamic range the system could saturate in presence of direct or reflected sunlight, or high-	CATAPULT, Performance Testing for Sensors in Connected and Autonomous Vehicles: Feasibility Study, 2020 [25]	M

		intensity vehicle lights. The effect of the saturation would be the loss of the ability of the camera to detect any targets either in a portion or the whole of the field of view. In order to identify the failure due to saturation of the dynamic range of the sensor a test should be performed using a suitably intense photometric source e.g. CIE Illuminant A, the emitted power and temperature should be well calibrated so that the power incident on detector is known. Suitable illuminated test charts should then be imaged, e.g. ISO 15739:2017 and ISO 18844, to determine performance" [25], page 34		
EL40	The system will continue to work even though one of the sensors / cameras fails.	FOVs of two cameras will be overlapping the view directly in front of the vessel so that in case one camera fails, the most relevant view is still under observation. "Redundancy for cameras may be covered by a PTZ camera able to navigate to the scene of several static cameras or by a positioning of cameras, where the field of view of one camera is part of the following camera at a lower quality level." [20]	IEC 62676-1-2, 2014 [20]	M
EL41	The system shall monitor and detect any failures of the essential functions.	The system should be aware of how its devices and functions perform, especially critical ones. For example, monitoring the nitrogen level inside the camera housing and notifying if it drops too low. "For security grades 3 and 4 the VSS shall manage device failure by indicating any failure of the essential functions within 100 s of the failure." [20]	IEC 62676-1-2, 2014 [20]	M
EL42	The system shall provide methods for controlled access to data.	Only authorized persons are allowed to have access to the collected video and data. GDPR applies in Europe.	IEC 62676-1-2, 2014 [20] General Data Protection Regulation, 2016 [26]	M
EL43	The system shall provide a method to verify integrity of the data.	Since the (video) data is essential for the functioning of electronic lookout, it is critical that there are ways to verify that the data is not altered or tampered with. Such methods include watermarking, fingerprints and checksums. "The authentication method shall be applied at the time the data is recorded and shall notify the user if any of the following has occurred: • any of the images has been changed or altered;	IEC 62676-1-2, 2014 [20]	O

		• one or more images have been removed from a sequence; • one or more images have been added to a sequence; • the data label has been changed or altered.” [20]		
EL44	Image export	“The images shall not be encrypted. The video format can contain checksums or other methods for ensuring that changes to the data may be detected but, where used, they may not alter the compressed image information” “The compressed images (and audio if present) shall be encoded using standard compression formats (see IEC 62676-1-2 or Annex A “current video standard formats”). The compressed data shall comply strictly with the standards and contain the full information required to decode the images and audio.” [8]: Chapter 11.1	IEC 62676-4, 2014 [8]	O
EL45	Cyber security	The computer based systems and networks should be compliant with the applicable requirements related to the assignment of the additional class notation CYBER SECURE from Society Rule Note NR659, Cyber Security for the Classificationof Marine Units.	BV NR659, 2023 [27]	M
EL46	Image quality	“The imaging chain – consisting of image capturing, codec, transmission, handling, storage and display – shall be tested according to 6.1 of ISO 12233:2010 (see Figure 5). The results shall be documented and reported according to Clause 7 of ISO 12233:2010.” [20]	IEC 62676-1-2, 2014 [20]	M

3. Conclusions

Part of the requirements presented are based on real-life tests done at Harmaja Maritime Pilot Station during spring 2023. The set of cameras described in Table below was directed towards the open sea to record video stream of passing vessels. Data was collected in all kinds of circumstances encountered, but for testing and development of detection only clear weather images were used. The aim was to investigate from how far away the vessels can be detected (see Figure 1) with selected cameras and currently available detection methods (basically, YOLOv5). At the time of writing YOLO is widely used in applications requiring real-time detection and high accuracy. It’s particularly useful in scenarios where detecting and classifying objects quickly is crucial, like in autonomous vehicles, surveillance systems, and various forms of real-time video analysis.

More detailed specifications of the cameras are presented in Table 7 but few things are highlighted here. All the cameras have Sony CMOS sensor in a couple of different sensor sizes. Each camera also included optical zoom with maximum zoom varying from 23x to 57x, i.e. 177 mm to 850 mm focal length

(FF equivalent 563 mm – 4080 mm). The ViewSheen camera does not have built-in panning or tilting, but such an equipment was implemented separately, so that the camera could also be remotely directed as required. The ViewSheen camera with its 100 mm diameter lens and 1/1.8" sensor provided the brightest images.

Table 7 Specifications of cameras used in Harmaja tests.

	Milesight AI PRO PTZ Bullet Plus 5 MP 23x	**BirdDog A300 Gen 2**	**ViewSheen VS-SCZ2057NO-8**
Image sensor	2592×1944@30 fps (H.265) 1920×1080@24 fps 1/1.8" SONY CMOS 9mm diag, crop factor 4,8	1920×1080@60 fps 1/2.8" SONY CMOS 6.5 mm diag, crop factor 7.2	1920×1080@25/30 fps 1/1.8" SONY CMOS 9 mm diag, crop factor 4.8
Optical zoom & lens	23x Focal length 5 – 117 mm FF equiv. 24 – 562 mm f/1.5 – 3.5 HFov 60.0° – 3.0° Lens diameter 30 mm	30x Focal length 4.3 – 129 mm FF equiv. 31 – 929 mm f/1.6 – 4.7 HFov 63.7° – 2.3° Lens diameter 35 mm	57x Focal length 15 – 850 mm FF equiv. 72 – 4080 mm f/2.8 – 6.5 HFov 29.1° – 0.5° Lens diameter 100 mm
Gimbal / stabilizer	Digital stabilization	–	Optical electronic
Video codec	H.265 MJPEG (~22 000 kbps)	H.264 (~130 000 kbps)	H.265 MJPEG (~22 000 kbps)
Panning	Hor.: 360°, Ver.: +30° to -45°	Hor.: 360°, Ver.: +90° to -30°	-

An example of the recorded data, a case of Tallink MyStar (MMSI 276859000) passing was chosen to be presented here in more detail. It has gross tonnage (GT) of 50 629 and passed the measurement location about 19 km away. At the time of the measurement the wind was of Beaufort scale 1, and the day was clear and cold.

For detection we used a special YOLOv5 model trained especially with maritime and vessel data. This model was able to find MyStar at the 19 km distance from each camera's image data with confidence level of 0.38. The smallest bounding box of 7x11 pixels was produced from Milesight images. It is notable that zoom levels used in these detections were low, from 1.1x to 5x.

Additionally, Viking XPRS (MMSI 230705000) of 35 918 GT was detected at a distance of 20 km from ViewSheen data. Confidence level for this detection was 0.67 and vessel size was 7x12 pixels.

When considering these results together with the requirements defined in previous section, it is possible for the currently available detection methods and cameras to reach the detection requirements set for a lookout within the specified operational envelope of the electronic lookout. The example vessels presented here have GT over 5 000 and their minimum height is larger than 10 meters. Thus, they fall under the requirement EL25 that sets the minimum detection distance for such a vessel to be 20.4 km.

Additionally, the environmental conditions in the example cases meet the requirements set for the operational envelope of the electronic lookout. For the test setup, the relevant requirements from that section are EL1, EL3 and EL5. These cover environmental conditions, which were met in the example cases presented earlier. The cameras monitored open sea environment (EL1), Beaufort scale was at level 1 (EL3) and there was enough light (EL5).

Test performed in Harmaja indicate that with the currently available technology it is feasible to monitor vessels at sea. Furthermore, it is predictable that the development of cameras will continue, and their resolution will increase. This might lead to diminished need for optical zoom in the future. Additionally, AI detection methods are improving rapidly thus providing even better and more reliable results from more obscure data. However, training data and its quality is crucial to AI methods as was perceived also in our results. A specifically trained custom model provided better results than the YOLOv5 with basic trained model.
As a first step, the operational envelope of the electronic lookout was limited to clear weather with Beaufort scale 0 – 3. Therefore, more challenging environmental conditions have not been experimented nor addressed in this document. Especially with camera-based approach the lower visibility due to bad weather will decrease the performance level of detection and brings challenges to automate the lookout tasks. In addition, movements of vessels from scale 4 upwards pose new challenges for the stabilization of equipment.

4. Summary

This report is a first of a kind collection of requirements to guide the implementation of an electronic lookout in maritime. Such a system, which could be used as an aid for officer of the watch in limited conditions (offshore in good weather) on some types of vessels. The system would act as a tireless observer of the environment and would raise an alarm when it notices something out of the ordinary in the surrounding sea area. A proposal for the first installation site could be a cruise ship where the navigation bridge may be quite large. There, electronic lookout would reduce workload, i.e. the need for the officer of the watch to move from one place to another in some circumstances.

Field tests showed that with today's cameras it is possible to achieve the needed performance. Computer based detection is heavily dependent on the trained detection database models available. The better the trained model is, the better the detection performs. Since more and more training material is accumulated and algorithms are trained, the detection reliability can be expected to improve. This eventually leads to a performance level where different kind of marine objects; vessels, markers, and buoys etc. are recognized and classified, and not just detected as something other than water.

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