The Bridge Zero concept and the lookout requirements

Lookout requirements for Bridge Zero (B0) – a conditionally and periodically unattended bridge – can be met by technology.

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When assessing the possibilities to define a machine-based lookout for use in ships in international commercial traffic, it quickly becomes apparent that the current legal system needs some adjustment. The provisions in SOLAS, STCW 2010 and COLREG are very descriptive with the weight of definitions in matters such as the construction of the bridge, the eyesight and hearing of an able seaman or rating of the watch. In a goal-based system, we would prefer a functional description with the minimum levels of information input defined.

Originally the navigation watch consisted of the officer of the watch, the lookout and the helmsman. If the situation demanded it, the watch could be extended with the master, a pilot and an additional lookout. In this paper the task is to evaluate the possibilities and challenges in substituting the function of the lookout with a technology-based system.

In general, the practice of automating functionalities in the marine industry has a requirement to achieve "equal or better" level of safety with the automated system in comparison to the manual system. Therefore, the main challenge is to define the current level of safety. Human performance is defined rather vaguely and depends significantly on the individual, state of health, alertness, time of day, environmental conditions, etc. This makes defining the current performance level not at all straightforward. In the current regulatory system, there are no quantitative threshold values which would define the minimum performance level. In order to define the requirements for the technology that would achieve "the same or equal" performance as the human lookout, such definitions are needed.

This paper discusses the performance of the lookout function from the available sensory input data and associated fundamental limitations presented by the human lookout, as well as indicates that equal level can be achieved by means of technology. In addition, the focus is not on the audible sensory input, as it has been already accepted since the introduction of closed bridges that the audible signals can be provided by the so-called 'elephant ears' – a sound perception device [1]. The main challenge from the regulatory perspective today is in substituting the human eyesight and decision making based on the sensory input.

The paper mainly focuses on the open sea navigation tasks with no land in sight and where other vessels are generally far away. The objective is to propose that the lookout requirements related to the B0 situation – a conditionally and periodically unmanned bridge – can be achieved by the means of technology.

Tasks and requirements of the lookout
The purpose of the lookout is simple. So simple, in fact, that it is sometimes overlooked. As the purpose of the navigation rules is to prevent collisions, it follows that the purpose of the lookout

is to collect the information required to avoid collisions. This fundamental reason for maintaining a proper lookout is something to keep in mind. The function of the lookout can basically be divided into two specific areas: the safety of the own vessel and the safety of everyone else in the vicinity.

According to the current regulatory system, the tools of the lookout are sight, hearing, and 'all available means'. It is also stated that the lookout shall have the mental capacity to interpret the information available through the means at hand. It also goes without saying that the function has no meaning unless the information can be relayed to the officer of the watch in an orderly fashion with the best possible accuracy.

STCW 2010 Medical requirements for duty on deck:
- Vision (appendix A), hearing (appendix B) and physical capabilities (appendix C)
- Impairment from the use of medication (appendix D)
- Presence or recent history of an illness or condition (appendix E)

The functionality of the lookout can and should be described as assisting the officer of the watch to obtain the best possible situational awareness with regards to the operating environment. The description of the function of a lookout is as follows: "Maintaining a continuous state of vigilance by sight and hearing as well as by all other available means, with regard to any significant change in the operating environment" at all times in all weather conditions both day and night. 'Significant' in this context refers to the relative quality of the information input to the officer of the watch and will be one of the key topics. This part of the code is hard to translate into an algorithm but at the same time may be the most important part.

"Fully appraising the situation and the risk of collision, stranding and other dangers to navigation" is key to the safety of the own vessel and rather well understood and rather straight forward.

"Detecting ships or aircraft in distress, shipwrecked persons, wrecks, debris and other hazards to safe navigation" describes both the safety of the own vessel and the safety of others. This has also been one of the most discussed parts in the discussion of MASS. How do we ensure that any party in distress in high seas will receive the best possible chance of being detected and recovered? The requirement will need to encompass a degree of image and pattern recognition.

Today we can already periodically and conditionally merge the functions on the navigational watch to only the officer of the watch performing all the duties described as the functions for safe navigation. This has only been possible with the evolution of supporting technologies. The requirement of hearing, as mentioned earlier, has already been substituted with technology approved by the International Maritime Organization.

It is to be noted that the helmsman was always to act only as the helmsman which means he or she could not be tasked with the function of lookout. Later with the development of navigational aids such as the autopilot the helmsman could be dropped from the muster list provided that the vessel is equipped with a functional and approved autopilot.

One specific task that should be included in the future definitions and possible rule change would be the detection and reaction to a 'man overboard' situation.

Current performance of human lookout – sensory input for decision making

Modern SOLAS ships have mandatory navigational equipment for assisting in determining the position, heading and detecting the relevant obstacles in the surroundings. In practice, the vessels typically have radar, gyrocompass, ECDIS, GNSS-based positioning system and an AIS receiver. In addition to these devices, the lookout uses his or her own senses, mainly eyes and ears to perceive the surroundings. If hearing is disregarded due to the already existing acceptance of the electronic hearing devices, the main sensory input for targets that are far away, in addition to the above-mentioned navigational equipment is the human vision.

Human eyesight performance

Human eyesight performance depends on the eye health, the visual acuity (clarity of the vision), light and obstacles (such as fog) in the line of sight, as well as the target the human is looking at. Defining the current level of eyesight performance of the human lookout from the physiological perspective is not unambiguous and is therefore not addressed in detail in this paper. Instead, this paper adopts a common definition of the human eyesight angular resolution, which is approximately 1 arcminute [2]. In practice this means that human can distinguish an object from a point or another object if the object extends 1 arcminute (0,0167 deg), when focused. The reason to choose this criterion is that in the marine environment, the background is always textured and dynamic due to the sea surface and light conditions. Therefore, the target smaller than 1 arcminute criterion will most likely not be distinguishable from the textured background. This means that the further the object is, the larger it needs to be in order to be detectable by a human. The practical aspect of the human eyesight resolution definition adopted in this paper is illustrated in Figure 1, where the human eyesight resolution is denoted by:

$$\alpha_{res,h} \approx 1\ arcminute\ \approx 0{,}0167°.$$

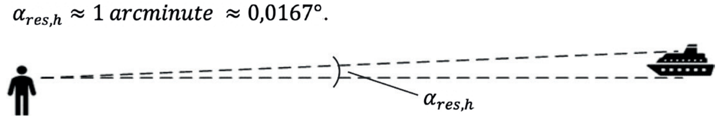

Figure 1: Illustration of the human eyesight resolution

Fundamental boundary conditions

From the perspective of physics, there are two main aspects which fundamentally limit the ability of a human lookout to detect targets from the bridge. Namely, the curvature of the Earth and the meteorological visibility. In perfect visibility conditions, the maximum range of the human vision performance to detect targets is limited by the curvature of the Earth, provided that the object is large enough to be detectable by a human. In order to determine quantitative boundary values for the performance of the human lookout, very conservative fundamental limitations can be set by the visibility and the curvature of the Earth.

Limitation due to the curvature of the Earth

The curvature of the Earth limits the visibility of the targets in the horizon at open sea. The maximum distance that an observer with a height h_O can detect a target with a height h_T in a horizon can be approximated by:

$$D_{max} \approx 3{,}57 \cdot \left(\sqrt{h_O} + \sqrt{h_T}\right)\ km.$$

As an example, consider an observer at height of h_O = 30 m and an object of height of h_T = 30 m. In this setup, the distance the object disappears below the horizon is approximately D_{max} = 39,1 km. Target of the same height further than this will disappear below the horizon due to the curvature of the Earth.

Combining the curvature of Earth limitation to human eyesight resolution

Combining the curvature of Earth limitation with the minimum angular resolution of human eyesight, it is possible to calculate the practical maximum range of a target above the horizon that is detectable by a human. This can be achieved by matching the maximum distance and the resolution. The height of the object $h_{T,r}$ at distance $D_{max,h}$ matching the human eyesight resolution $\alpha_{res,h}$ can approximated by:

$$h_{T,r} \approx \alpha_{res,h} \cdot D_{max,h}.$$

Combined with the distance approximation due to the curvature of Earth so that the object is $h_{T,r}$ above the horizon, one obtains:

$$\begin{cases} D_{max,h} \approx 3{,}57 \cdot \left(\sqrt{h_O} + \sqrt{h_T - h_{T,r}}\right) \\ h_{T,r} \approx \alpha_{res,h} \cdot D_{max,h} \\ 0 \leq h_{T,r} \leq h_T \\ D_{max,h} \geq 3{,}57 \cdot \sqrt{h_O} \end{cases},$$

Solving $D_{max,h}$ from the equation gives the approximation of the range a human can detect.

As an example, considering an observer with h_O = 30 m, combined with the human eyesight resolution, a h_T = 30 m high object becomes distinguishable for a human when the object is approximately at $D_{max,h}$ = 35,4 km distance. In this distance the object is $h_{T,r}$ = 10,4 m above the horizon, which is approximately 1 arcminute in angular resolution from the observer. The principle of the calculations is illustrated in Figure 2.

Limitation due to the visibility

The visibility in the lookout context defines the distance by which an object or light can be clearly discovered. The visibility can be decreased by fog, haze, rain, etc. disturbance which absorbs, scatters or blocks the visible light wavelengths and therefore decreases the visible range. The definition of visibility as a range is not unambiguous as it depends on the target properties, light conditions, etc. Therefore, this paper assumes that if the target is further away than the visibility range, a human lookout cannot detect it. On the other hand, if the target is closer than the visibility range, the human lookout can determine it. Therefore, this paper assumes that the visibility sets the maximum range that the human lookout can detect an object relevant for performing the lookout function.

Implications and minimum requirements for technology – minimum sensory input for machine-based lookout

As discussed above, the sensory input for the officer of the watch are the SOLAS navigational aid equipment as well as the human eyes of the lookout. As the SOLAS navigational aid equipment is already digital, the main challenge is to define the technological requirements to achieve "as good or better" detection performance by visual means. The most advanced, yet commercially feasible technology to achieve the visual perception is camera technology, equipped with computer vision. In the following, the camera technology requirements are analyzed based on the chosen resolution criterion and the limitations set by fundamental boundary conditions, mainly focusing on the good visibility situation where the main boundary condition is the curvature of the Earth.

The human lookout performs the sensor fusion, that is, combining the sensory input from each modality (visual, radar, charts, etc.) to determine the overall assessment of the situation manually. Given the resolution criterion and the boundary conditions as proposed in this paper, in order to achieve the performance comparable to human capabilities, the performance of the camera system should be able to detect targets using computer vision with 1 arcminute resolution up to the maximum distance limited by the curvature of Earth in good visibility conditions. In addition, the system needs to be able to detect targets up to the distance limited by the meteorological visibility.

If the above can be demonstrated, the minimum level of a lookout – that is, detecting the targets – is shown to be 'as good or better' than human.

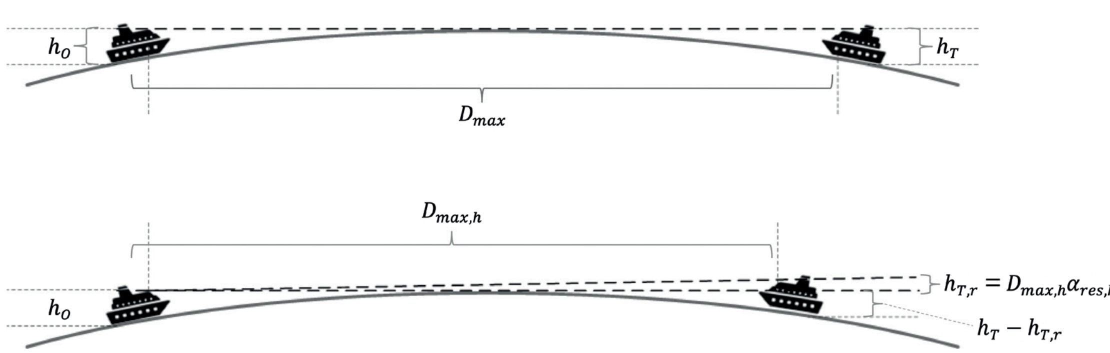

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Figure 2: Illustration of the limitation due to the curvature of Earth (top) and the decreased maximum range due to the human eyesight resolution (bottom).

Comparison of camera technology and human performance

In camera-based surveillance and monitoring, there are standard, accepted ways to estimate the maximum range a camera system with given specifications can monitor, detect, observe, recognize, identify an object. The IEC standard 'IEC 62676-4 Video surveillance systems for use in security applications – Part 4: Application guidelines' defines the requirements for each of the surveillance task. Detection is defined as an ability to detect a presence of an object. This is essentially the primary task of the lookout function, that is, detection the presence of targets which are 'something else than water'. With the digital camera technology, the different tasks such as detection, recognition and identification are determined by the number of pixels. The minimum projected dimension of an object needs to be represented in the picture in order for it to be able to detect, recognize or identify the object.

The threshold for detecting a human presence (0,5 m x 1,7 m) is 25 px/m, where px refers to number of pixels. In practice, this means that the width of a human projection (0,5 m as a standard) needs to be represented by 12,5 pixels. Assuming that each dimension needs to be represented by 12,5 pixels in the picture, one can calculate the angular resolution and therefore the maximum range the camera could detect an object, possibly limited by curvature of Earth. The calculations can be done by modifying the formulae described above for human performance.

As an example, consider a Full HD Pan-Tilt-Zoom (PTZ) camera with resolution of 1920 x 1080 and zoom so that the minimum horizontal field of view is 2,3°, installed at 10 m height. The standard DRI detection criteria and the associated detection distance, taking into account the Earth curvature can be calculated for various marine-relevant targets as illustrated in Table 1. The detection distance with human eyesight is also estimated using the previously described formulas.

As Table 1 shows, the example camera setup can achieve equal or better resolution compared to the human eye. Obviously, there are several technical solutions which achieve the same through different configurations of camera and optical technologies. The purpose of the table is to illustrate that in good visibility conditions the camera technology can meet the criteria of human eyesight resolution.

Note that in practice both the human eyesight performance, as well as the camera performance is affected by several factors, including air quality, humidity, vapor, light conditions, contrast, color and reflectivity of the object, etc. Camera performance is also affected by clarify of the lens, the focus, mechanical vibration, etc. aspects not considered in this paper.

Experimental results and illustrations – experimental setup

In order to test the theoretical calculations, an experiment was performed. The experimental setup included ABB Ability™ Marine Pilot Vision situational awareness system installation with a full HD PTZ-camera and 30x optical zoom. The horizontal field-of-view of the camera with maximum zoom settings was 2,3°. The camera was

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Table 1: Comparison of estimated detection distance for various marine-relevant targets in perfect visibility conditions based on 12,5 px/minimum dimension of the object (full HD PTZ camera with 2,3° horizontal field-of-view installed at 10 m height) combined with Earth curvature limitation, and human eyesight resolution combined with Earth curvature limitation. Note that the calculations are based only on the height of the object, as that is typically the limiting dimension.

	Length (m)	Height (m)	Beam (m)	Detection distance – camera (km)	Detection distance – human eye when focused (km)
Small boat	4,7	1,0	1,5	3,8	3,4
Small pleasure craft	7,0	1,5	2,6	5,7	5,2
Medium pleasure craft	10,2	3,0	3,5	11,4	10,3
Small passenger ferry	33,0	6,0	8,0	16,1	15,6
Bunkering vessel	87,8	26,6	13,4	27,1	26,8
Ropax vessel	136,1	30,0	24,2	28,3	28,0
Medium range tanker	205,7	30,5	34,3	28,4	28,1
Aframax	246,9	33,5	41,1	29,4	29,2
Suezmax	289,6	45,7	48,3	33,0	32,8
VLCC	378,0	61,0	63,0	36,9	36,6

Figure 3: Two boats at 6,.8 km (leftmost the “Small pleasure craft” and rightmost the “Medium pleasure craft”). Picture below – the same boats at approximately 9,6 km. Note that the zoom settings of the pictures are different.

Figure 4: Deep neural network based detection of the ‘Medium pleasure craft’ at around 9,6 km

installed at the height of 10 m. The vessel where the camera was mounted was stationary during the experiment.

Two pleasure crafts with dimensions equal to the ‘Small pleasure craft’ and ‘Medium pleasure craft’ described in Table 1 were used as detected targets. The boats were navigated to a specific distance from the vessel where the camera was mounted. The weather was clear during the experiment with 4 m/s wind from north east. The air pressure was 1019 hPA and the visibility was good. The time of day during the experiment was 04:00 am to 06:00 am. The test was done in the Helsinki estuary.

According to the results, as illustrated in Figure 3, one could detect the boats with a camera even further than the standard detection criterion indicates. With the mentioned equipment, vessel size and the installation height of the camera, the ‘Small pleasure craft’ should be detected at around 5,7 km, whereas the boat is still detectable at 6,8 km. The ‘Medium pleasure craft’ could be detected clearly still at 9,6 km. Figure 4 presents the detection result of a deep neural network based image processing algorithm trained to detect vessels from background. As an example in this picture, the "Medium pleasure craft" is detectable at 9,6 km.

From detection to decision

The human lookout needs to manually process, remember and track the targets detected visually. The targets detected by AIS and ARPA radar are tracked by the machine. When the association of the information is done by a human, it is likely that if the situation persists, the human can forget the existence of some targets, which can lead to a wrong assessment of the situation. In machine-based lookout, monitoring the surroundings is continuous and relentless. The system keeps track of the targets, monitors and predicts their movements and does not forget information in a way a human might do. Moreover, the system is neither affected by the human mental state nor the limited capability of a human to process information and detect changes.

Beyond human performance

As discussed above, the minimum level for machine-based lookout performance is to demonstrate that the visual acuity in different boundary conditions match human performance. Modern perception technology allows to achieve performance beyond the human perception capabilities. For example, infrared (IR) camera technology enables the detection of targets in decreased visibility conditions, whereas the human eye cannot see even when using binoculars. Short wave infrared (SWIR) cameras enable detection of other vessels even through fog and long wave infrared (LWIR) cameras enable detection of other vessels, debris and floating obstacles even at pitch black conditions and decreased visibility conditions.

It is also important to recognize that the high-end technology that helps achieve the perception levels beyond the human performance increases the cost of the system, and therefore the additional benefit of achieving the ‘better than human’ level needs to be considered from practical and financial aspects as well.

References:
[1] SOLAS Chapter V regulation 19.2.1.8, minimum standards of ISO 14859:2012(en)

[2] Yanoff, Myron; Duker, Jay S. (2009). Ophthalmology 3rd Edition. MOSBY Elsevier. p. 54. ISBN 978-0444511416.