Lighting Future Naval Ships – Mission Optimized and Human Centric

Dr. G G Langer [a], N T Launert, MSc [b]

[a] *thyssenkrupp Marine Systems GmbH, Hamburg, Germany;* [b] *LINKSrechts GmbH, Seevetal, Germany*
*Corresponding author. Email: gerrit.langer@thyssenkrupp.com

Synopsis

Progress in lighting technology comes in waves: As the LED is emerging as the winner from the current wave, the digital transformation is pushing the limits of technical possibilities of lighting once more, as it gives access to more degrees of freedom in lighting. Advances over the last decade have significantly expanded the scope of lighting technology: 'Intelligent Lighting' yields several new opportunities. Through the advantageous properties of LEDs electric light will be a carrier for optical wireless communication. It finally will provide its users the lost qualities of a natural dynamic light environment as a surrogate of sunlight with all its stimulating effects, thus a 'Human Centric Lighting' addressing the biological needs of a ship's crew with limited access to daylight, increasing their well-being, health and performance on the job.

Keywords: Human Centric Lighting; circadian clock; non-image forming effects; light management systems; visible light communication; LiFi

1 Introduction

Light Emitting Diode (LED) technology has matured and become a capability driver. A light source of unprecedented properties compared to its predecessors: Higher energy efficiency, less waste heat, rapidly switchable, low voltage DC, inherently shock proof, low maintenance and prolonged lifetime, etc. The so-called "LEDification" of existing 'analog' light infrastructures becomes a matter of fact - leaving the LED as market-dominating (LightingEurope: Focus Areas). This is mainly driven by the efficiency aspects. The next wave of innovation (Figure 1) joins lighting and the digital world. It grants a large degree of freedom, by making physical light parameters readily accessible and help create new designs based on control and connectivity in lighting. This has a higher impact on infrastructures themselves. The notion of automation and intelligent management of lighting is to best serve users' needs and increase sustainability. Through the information layer in light management, the foundation is laid to realise yet more value to the users of lighting in the next wave: Functions such as Human Centric Lighting (HCL) with its positive health impact or Visible Light Communication (VLC, also: LiFi; Haas, 2011) with its promise of nearly unlimited bandwidth promote the embedding of man into his technical ecosystem. Under the terms 'smart building' or 'smart platform' a system of systems is conceptualised which governs all factors of the work and life environmment (ZVEI, 2017).

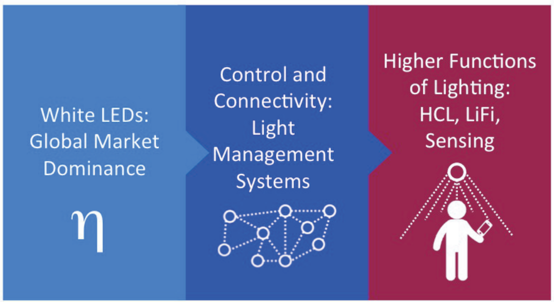

Figure 1: Successive waves of innovation in lighting technology.

In modern economies the continuous progress in scientific research and development leads to a constant redefinition of the state-of-the-art. The current digital transformation has the potential of increasing the pace and allows solutions to become more integrated and customer oriented. Light onboard naval ships – so far – has simply been a stand-alone environmental factor often designed in a 'traditional' fashion, while at the same time workplaces on modern naval ships are among the most costly on earth.

Authors' Biographies

Dr. Gerrit Langer is a project engineer in the department of research and development at thyssenkrupp Marine Systems GmbH. His research interests include machine learning and data modelling. He has previously been active in the field of macromolecular X-ray crystallography at the European Molecular Biology Laboratory. Dr. Langer graduated in applied physics from Georg-August-University of Göttingen in 1999.

Niels Launert MSc is a project engineer for naval ship lighting systems at LINKSrechts GmbH. His research interests include optical wireless communication through light and information technology. He graduated in electrical engineering and information technology from Christian-Albechts-University of Kiel in 2016.

http://doi.org/10.24868/issn.2631-8741.2018.022

Technological revolutions evolve quicker than the biology of the human species can adapt to. This has lead to an increasing maladjustment to the man-made environment: As a result of evolution mankind has adapted to the day-night cycle and all aspects of human performance exhibit a circadian variation. The sleep-wake cycle is the most visible manifestation of this (Figure 2). Inferring the time of day from external factors such as lighting used to be critical to survival and possessing an 'internal clock' with predictive capabilities, as a regulator of physiology and behaviour, proved an evolutionary advantage (Vaze and Sharma, 2013). In modern civilisation, through artificial lighting, human activities are no longer restricted to natural daylight times and the function of light, as an indication of time, has weakened. In fact it can have a disruptive influence on circadian rhythmicity with possibly detrimental consequences for health (Roenneberg and Merrow, 2016). However, light is the primary stimulus that synchronises the circadian clock (Brown, 2016) and it triggers a number of acute effects, too, e.g. increase of alertness or heart rate (Cajochen, 2007). The collective term of the 'Non-Image Forming' (NIF) effects of light encompasses these 'biological' light impacts. Taking NIF effects of light into account in the design of lighting compatible with human biological needs leads to Human Centric Lighting. Practically implemented, HCL approximates the properties of daylight and exploits the mechanics behind the NIF effects: It can achieve a stabilising effect on human physiological rhythms, thereby enhancing performance and improve overall well-being.

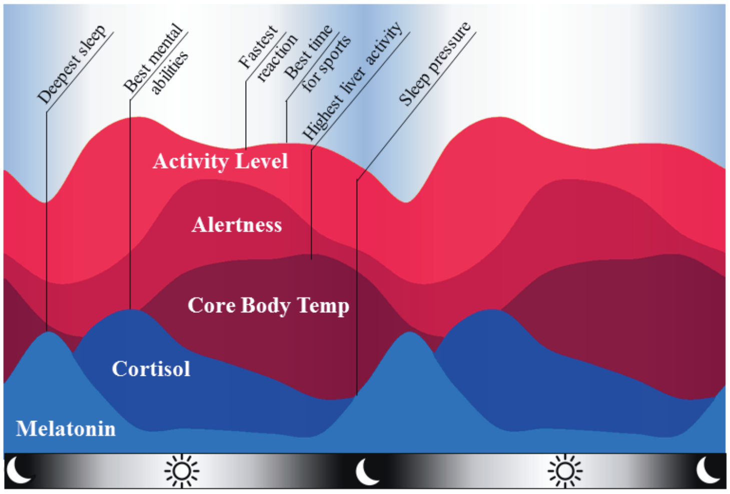

Figure 2: The relative amplitudes of circadian physiological indicators over two days (compiled from: Graf, 1960; Van Bommel and van den Beld, 2004; licht.de, 2018).

Optimising human factors in ship environments, where sailors spend most of their time under artificial lighting, in the authors' opinion plays a key role in maximising missions' outcomes (and safety), since all performance relies upon the cognitive and behavioural repertoire, arising from human biology. The objective of this article is to inform the readers and stakeholders, especially those with a naval (engineering) background, by portraying, combining and highlighting some relevant aspects from research and development on modern lighting to promote interdisciplinary approaches to future naval ship design. An emphasis is placed on the biological impacts of light with a summary of some relevant background knowledge in section 2. In section 3 the key aspects of a practical implementation of HCL on a naval vessel is discussed. Section 4 touches on new features of lighting systems in view of their continued digitisation. Finally, section 5 concludes with some wrap-up statements.

2 Biology of Non-Image Forming Effects

Human eye-sight is an adaptable, multi-layered, detection and classification mechanism. It can handle irradiance levels spanning 10 orders of magnitude. The light entering the eye through the cornea forms an image on the retina providing a stimulus for rod and cone photoreceptors (Figure 3a: grey and red elongated cells). Inner-Retinal processing completes at an output layer of ganglion cells (blue cells), that combine different neural input signals and act as line drivers on the visual nerve. A few of these ganglions (dark blue cells) all over the retina, are intrinsically photosensitive (Hattar et al., 2002; Berson et al., 2002) through their photo pigment melanopsin: They combine rod and cone input signals, as 'normal' ganglions do, and add their own light induced response. This intrinsic light response persists and dominates under bright light conditions, the ideal characteristics for tracking slow environmental irradiance variations (Gooley, 2010; Lucas, 2013). Their outputs are directed to the Supra-Chiasmatic Nuclei (SCN, Figure 3b: red circle), where the master circadian clock is located. Under free-running conditions (e.g. extended dim light situation) the clock would roughly approximate the 24h cycle. Light signals, though this pathway, synchronise the clock and trigger other NIF effects (Morin and Allen, 2006; Brown, 2016).

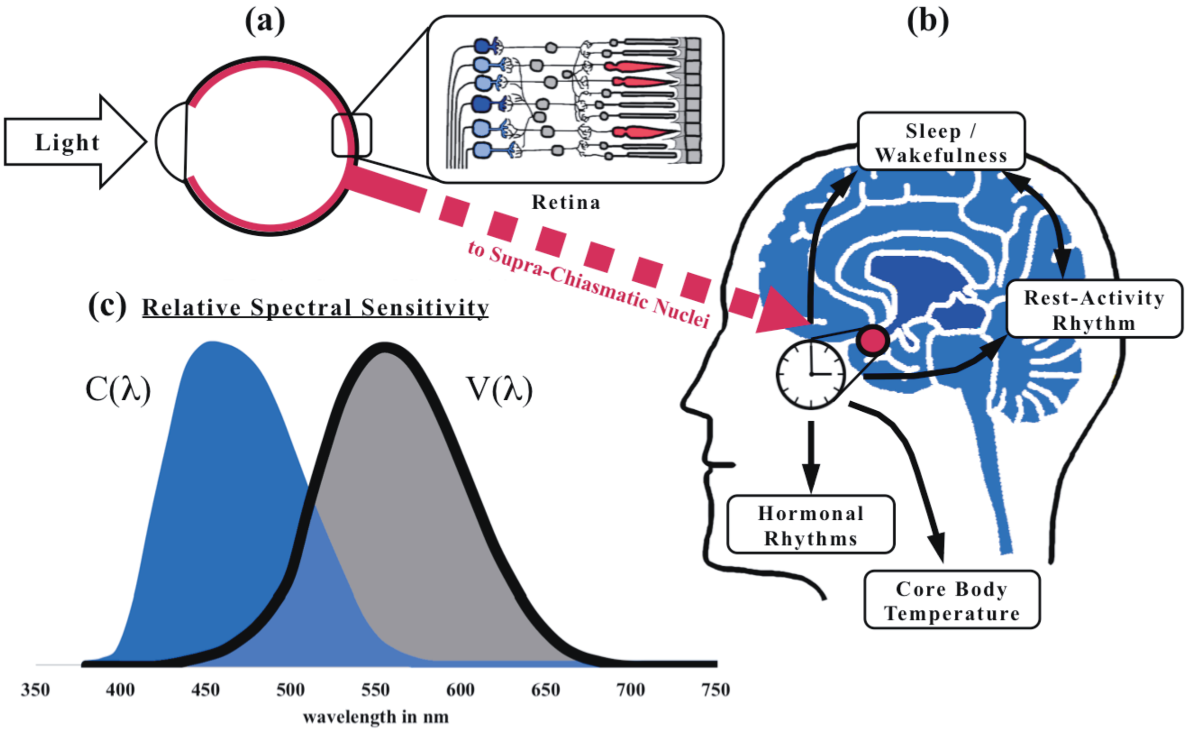

Figure 3: Light sensitive retinal ganglion cells (dark blue) send environmental irradiance information to synchronise the central pacemaker situated in the Supra-Chiasmatic Nuclei (red circle in brain). The (normalised) spectral sensitivity profile of the triggered effects C(λ) is blue shifted compared to the (photopic) sensitivity V(λ) of the 'classic' visual photoreceptors.

2.1 NIF Effects influence Human Performance

The SCN neural cluster itself possesses plenty of outgoing neural projections in its subcortical neighbourhoods. It triggers an array of neurological and physiological responses to light in this way, the NIF effects mentioned above. Some are achieved through a regulation of physiology and behaviour at a hormonal level (Kalsbeek et al., 2006), others through direct neural connections (e.g. to regulate the pupillary reflex). Such links to (higher) cortical brain regions modulate alertness and cognitive abilities (Cajochen, 2007; Vandewalle et al., 2009). In view of their optical trigger NIF effect strengths depend on certain properties, e.g. the spectral composition, of light entering the eyes: The spectral sensitivity profiles, so called action spectra, have been observed experimentally under laboratory conditions for different situations. A well investigated effect is, e.g. the suppression of melatonine, the 'sleep hormone', by light. This effect shows sensitivity to brightness, wavelength and some other factors (Thapan et al., 2001). Where the visual sensitivity function V(λ) (Figure 3c) is highest around 555nm (green), it was found that the sensitivity function C(λ) of most NIF effects (circadian entrainment, melatonin suppression, etc.) is blue shifted to around 460nm (Lucas et al., 2014).

The majority of human (physiological and neurological) activity parameters display concerted circadian oscillations in sync with environmental timers: E.g. Melatonin is produced at night, it slows down metabolism and induces sleep; cortisol, on the other hand, produced in the morning, accelerates metabolism and mobilises energy resources for day-mode (Figure 2 above). The 'mechanics' of NIF effects captures how such parameters are influenced by light quantitatively: Individual parameters can respond quickly to stimulating light - these are acute effects; delays or advances of the timing pattern of entire groups of parameters are phase shifting effects. Parameters such as melatonin respond in both ways. During the last decades a number of systematic lab studies have been carried out, which relate light scenarios to observed parameter changes in an attempt at quantification. Scenarios are usually described in terms of luminous and temporal 'light factors': Spectrum, quantity, directionality, and timing, duration, history respectively (Khademaga et al., 2016). Table 1 below summarises these factors, their influence and possible quantifications. Acute effects, in particular, following sufficient retinal irradiance levels and durations (see Table 1) can occur within seconds to minutes and outlast their stimulus by more than its duration. They possess a more or less pronounced dependency on the time of day. Table 2 below lists a selection of some relevant effects together with timing information. It must be noted here, that the mechanics of NIF effects at present are not fully clarified and are a matter of ongoing research. It is of utmost importance to have every detail of an experimental setting documented for later reproducibility. The introduction of light factors has proven very valuable. However, the 'correct' recording of the light factor 'quantity' seems a challenging topic (Aarts et al., 2017), as accurate corneal irradiance measurements are, what count in the end.

Table 1: Overview of the relevant aspects of light factors.

Light factor	Influence	Quantification
Spectrum	Maximal effect strength on e.g. melatonin suppression (Thapan et al, 2001) and many acute effects (Cajochen et al., 2005).	460…480nm (blue light).
Quantity	Circadian phase shifting and light dose influence (see below), illuminance dependence of melatonin suppression (Zeitzer et al., 2000).	Effect measurable at 100lx; 1000…2500lx (for full suppression to daytime values, response saturates).
	Acute reponses: Increased alertness, wakefulness, cognitive abilities, improved reaction times etc. (Cajochen, 2007; Vandewalle et al., 2009).	>1000…10000lx (in connection with duration!).
Directionality	The effect strength depends on where the retina is illuminated (Glickman et al., 2003; Rüger et al., 2005).	Highest for inferior, nasal region; less dependence of most acute responses.
Timing	Circadian phase shift depends on time of exposure (Khalsa et al., 2003); acute effects at any time.	Evening light (strongest from 8 to 10) delays, morning light (strongest from 3 to 6) advances circadian phase; No effect around noon and midnight. Cortisol stimulation in the morning!
Duration	Light dose scales approximately as time integral of intensity (Chang et al., 2012).	1000lx → ~30min 10000lx → ~3min
History	Circadian photoreception adapts to prior light exposure (Hebert et al., 2002).	Long and short term adaptation: After bright week in >5000lx, melatonin suppression by nocturnal light reduced by 20% compared to dim days (<200lx).

Table 2: Acute effects depend on the timing of the light stimulus.

Effect	Morning	Day	Evening	Night
Melatonin suppression	●		●	●
Increased heart rate and core body temperature	●		●	●
Reduction of sleep inertia	●			●
Increased cortisol production	●			
Increase in alertness, cognitive abilities, sustained attention	●	●	●	●
Reduced sleepiness		●	●	●
Improved reaction, psychomotor performance and lower error rates	●	●	●	●

2.2 Circadian Disruption

Under ‘natural conditions’ a steady state of the circadian system prevails and a daily programme is run in which there are optimal times for working, socialising, eating, etc. (see again Figure 2 above). When people spend extended time in artificial lighting conditions, the biological clock can get out of sync, because light exposure is in conflict with the clock phase. Omnipresent lighting often means that people are not getting sufficiently strong circadian timing stimuli. Light exposure in the evening delays melatonin-onset and makes it harder to fall asleep; it delays the circadian phase, whereas exposure early in the morning advances it. A disruption of the circadian system is seen as a potential cause to a multitude of pathologies, like e.g. obesity, decreased fitness, sleep-wake-disorders, cognitive deficits or even cancer (Roenneberg and Merrow, 2016; West and Bechtold, 2015). Some light related stimuli leading to unwanted effects can readily be named (Figure 4).

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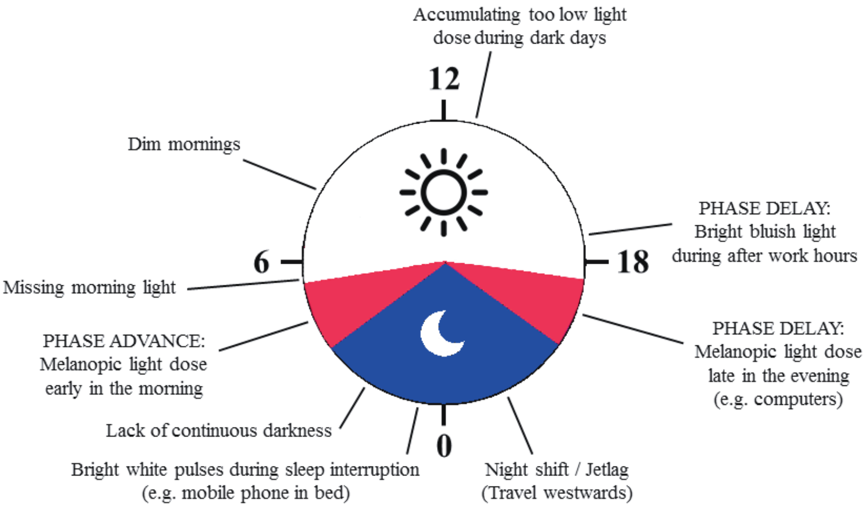

Figure 4: Undesirable timing stimuli through out-of-phase lighting.

2.3 Lighting Recommendations for improved Human Performance

The task is to design a light environment for a naval vessel that enhances effective circadian entrainment and raises the crew's alertness and cognitive abilities when needed. In doing so the lighting quality inevitably gets closer to daylight, as this provides physiological and psychological benefits. It is dynamic in intensity, colour and direction. A positive effect of such (diurnal) variability on mood, activation and performance has previously been reported (Vallenduuk, 1999). One is therefore well advised to manage lighting in a way that simulates daylight characteristics and achieves comparable benefits (Van Bommel and van den Beld, 2004; Rosemann, 2015). In such a lighting concept it is important to consider the whole 24h cycle and not just the 'worktime' hours. A 'best-practice day' like a recipe for good lighting derived from previous observations is proposed in this subsection.

In a natural setting morning light has a high portion of direct light illuminating the entire retina (caused by the sun's position in the sky) contributing to observed acute effects. The wake up period is a sensitive phase, melatonin should be suppressed and cortisol levels should rise. Bright white light in the morning acts as a stimulant, which accelerates the metabolic switchover to day-mode. An artificial dawn prior to wake up (30min, 0-250lx, ~2700K) was reported to successfully reduce sleep inertia (Gimenez et al., 2010). The post-wake up morning light-boost should then continue at levels >1000lx (>5000K, cold white), while cortisol levels reach their maximum and the morning high-phase sets in.

Most of the time during the day direct light comes from steeper angles and the 'sky dome' in addition is an intense diffuse 'cold white' light source. Daylight illuminances usually range between 10000lx and 100000lx. At a horizontal viewing angle such sky light only hits the inferior part of the retina; consequently this region shows highest effects in melatonin suppression and phase shifting (Figure 5 – despite light sensitive ganglion cells being distributed all over the retina). In an artificial 'designed' environment, to enhance circadian entrainment, it is important to provide distributed light to resemble the natural antetype: Diffuse ceiling illumination combined with worktop and direct illumination (Figure 6). However, most design specifications today only define illuminance levels on horizontal work planes.

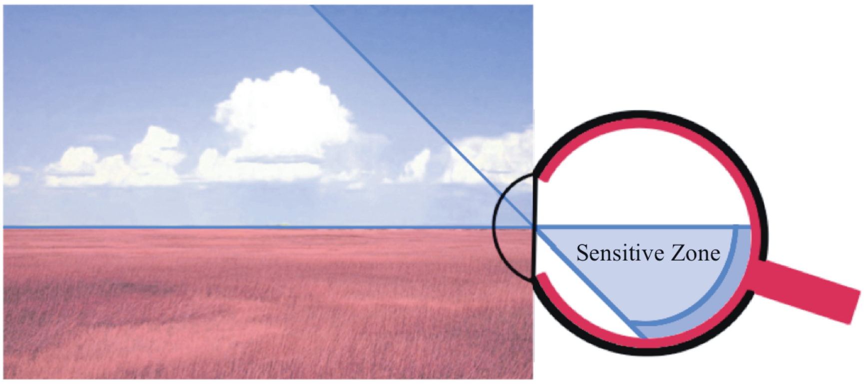

Figure 5: For circadian entrainment directionality and distribution of light should follow the natural antetype.

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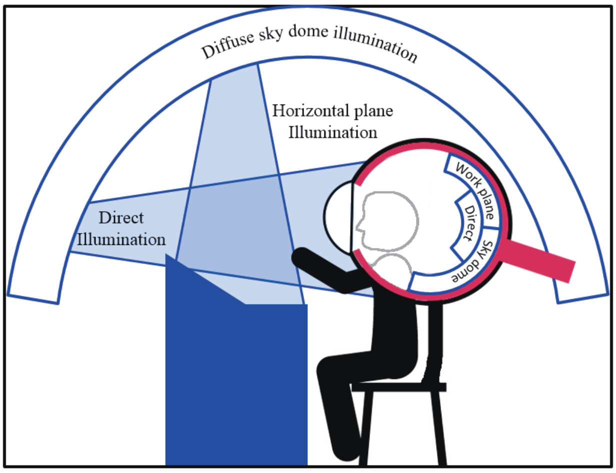

Figure 6: Distributed light is required in an effective lighting scenario. Key quantities are ambient diffuse lighting, direct lighting hitting the eyes frontal and horizontal work plane illumination.

Various studies indicate that high daytime illuminances (1000-2000lx direct, 800-1000lx horizontal plane, dynamic colour 2700K-6000K) are preferable (Aries, 2005) together with intermittent bright light pulses (1500-2500lx and 6000K-12000K) to stimulate alertness and achieve sustained lower sleepiness (Vandewalle et al., 2009). Afternoon bright light treatments for performance enhancement are reported (Phipps-Nelson et al., 2003). Overall high daytime illuminances (light doses) are also reported to improve sleep quality (Hubalek et al., 2010). The day light episode concludes with a higher direct portion (sunset), blue-reduced warm light, facilitating circadian entrainment and melatonin onset at nightfall. The combined recommendations in the form of a light factor timing scheme are shown in Figure 7. The ‘pseudo-natural’ lighting sequence contains ‘tactical’ intermittent phases for raising alertness or calming down during work breaks.

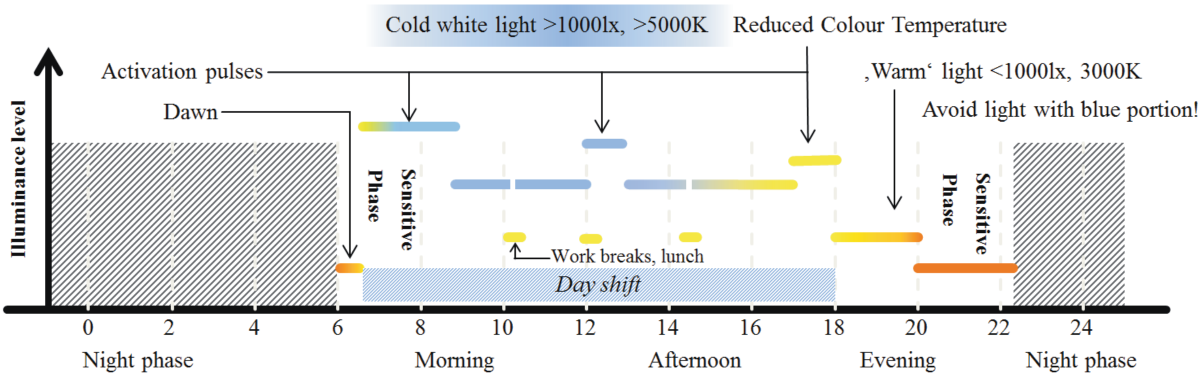

Figure 7: Best practice derived from previous research: the design day with respect to light exposure.

Regular night shifts, common in most navies, disrupt the circadian rhythm, leading to a potential shift of the circadian phase and cause sleep deficits. HCL is unable to compensate for missed sleep. It can do the following: Improve sleep quality during scheduled rest times by the phase-stabilising effect of sufficiently high light dosage at day time - reducing the sensitivity of the circadian phase to light stimuli at night time; shape transient lighting in a way to reduce detrimental effects and at the same time stimulate during the shift (Figure 8).

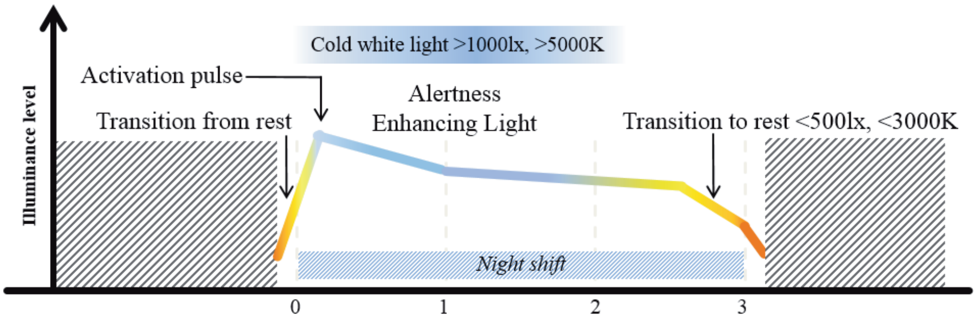

Figure 8: Suggested dynamics of light during a night shift.

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3 Practical Implementation of Human Centric Lighting on Navy Ships

A light designer needs to be in control of all light factors and their effects on users. For visual performance, the ‘photopic’ lux/lumen units, based on the V(λ) curve, provide standards for calculation and measurement. Concerning NIF aspects, the spectral sensitivity profiles of the effects considered need to be known beforehand. As an illuminance measure the ‘melanopic’ lux, based on the C(λ) action spectrum (Figure 3c) has been suggested (Enezi et al., 2011) with reference to its impact on many observed NIF responses. It is particularly useful to predict changes in melatonin concentrations and phase shifting (Novocin et al., 2017). There is a consensus among scientists to observe the so specified blue portion of light.

Practical lighting design commences with virtual prototyping and using light simulation.

3.1 Virtual Prototyping

Based on a CAD geometry of the ship and planned room furnishings, a lighting model is created by assigning optical properties to all visible (exposed) portions of the geometry. To satisfy specific lighting requirements, a suitable choice of luminaire types is decided for each room; their light distribution properties are added to the model. The resulting photopic/melanopic light distribution and the illumination of surfaces are computed with e.g. a radiosity method. While in general all rooms have more than one static lighting scenario this simulation gives a verification of a chosen configuration. Illustrations are routinely done to give a first impression (Figure 9).

Luminance ratios are relevant for the perception of luminous contrast and help visual tasks involving spatial orientation. This ratio should not exceed 10:1 between task related visual areas and their surroundings. Light sources in angular proximity to visual areas are suboptimal: Details hidden in excess brightness areas cannot be seen unless the eyes adapt. Luminous glare on reflecting screens causes visual discomfort and fatigue. A method for quantification is the Unified Glare Rating (UGR), which can be evaluated with most light planning tools today for ‘simple’ settings. However, several complex lighting scenarios cannot be assessed ‘automatically’: A human user needs to experience them. Virtual Reality (VR) techniques offer solutions for ship designers, creating photorealistic environments using computationally efficient game engines. These allow for qualitative evaluation of possible glare situations (Briede et al., 2016). An entire scene analysis can be carried out in VR to provide an immersive 3D experience and help identify risks and poorly lit scenarios.

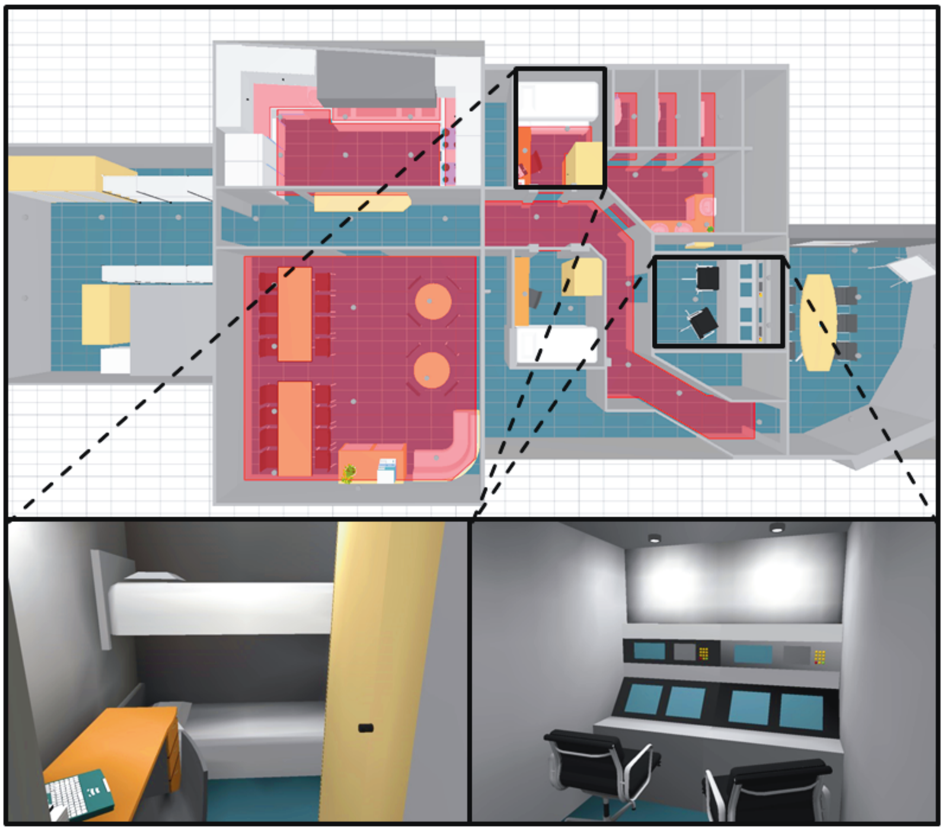

Figure 9: Example rooms arranged on the same virtual deck. Illuminance values calculated on surface elements are converted into a visual representation of the rooms and a particular lighting scenario.

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3.2 Human Centric Lighting

The objective is to offer the crew conditions that yield an improvement in their performance, fitness, well-being and health prospects. In this respect, HCL is a promising solution. The way in which HCL is implemented depends on the overall crew schedule: Are all members of the crew in the same circadian phase setting, or are parts of the crew constantly offset by 8 or 12hrs? In the first case a circadian dynamic in lighting, e.g. a 'Kelvin-Shift' function changing the colour temperature, is an appropriate solution, in the second different time- or circadian phase-zones, or possibly, a combination of both. Ideally, an implementation should provide all crew members with the light experience of the best 'practise day' (Figure 7) and be able to control light factors (Table 1) accordingly by means of light management systems (as part of platform automation) that can adjust each luminaire's intensity and colour temperature separately and in a time-dependent manner. The additional light factor of directionality can be realised through a combination of differently positioned light sources to create the subjective impression of a moving light source.

Apart from automation of lighting, users need some freedom for individual light settings. It is known that people with lower subjective alertness prefer brighter light. Therefore, a light management system should define intervals for luminous light factors appropriate for the time of day, time of night or the particular circadian phase of the user and provide access to alertness-enhancing light during shift work when demanded.

3.2.1 Recipe for Case Analysis

Provided that a lighting system design possesses the required degrees of freedom (luminous light factors) the time pattern of lighting, i.e. a lighting programme, can be compiled based on a case analysis: The view points and directions should be measured for representative crew members as a time series, the corneal irradiances can be measured in a real-world environment or be obtained from a virtual setting (see above). This results in a light history that, in comparison with the recommendations above, yields a quality assessment of a lighting scenario. As different crew members experience different days and light histories, the best lighting programme may only be found after careful studies and iterative optimisation (Figure 10).

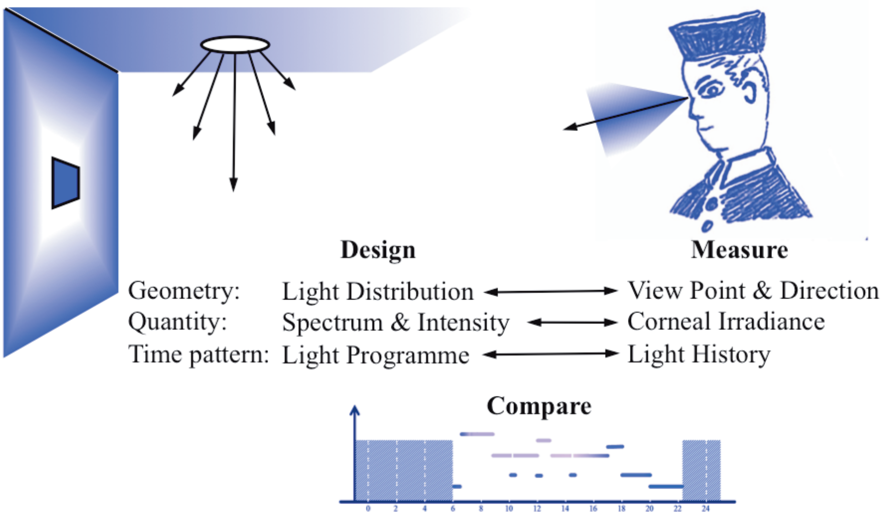

Figure 10: The recipe for finding the optimal light programme: Using the degrees of freedom of a lighting system to create the recommended light experience.

3.2.2 A Ship with Time Zones

When crews are divided in day- and night-groups, it is useful to arrange their duty-roster and the lighting in the respective work areas in a way that over a day the crews experience the appropriate light. A ship characterised by time zones may look as in the following example (Figure 11): The room lighting corresponds to a certain circadian phase / time: Work areas are lit brightly with activating and alertness enhancing light (>1000lx, >5000K); corridors and other transit zones are lit with bright warm white light (>800lx, 3000K); calm down and leisure areas have 'medium' brightness and a definite low colour temperature (<500lx, <3000K); finally sleeping areas are very dim and the colour temperature is again low (<50lx, <2000K).

In the example some 'representative' member of the crew visits several areas of the ship during his personal day. Each area's lighting produces the recommended light for the time of day when he is scheduled to be there (including activating light pulses at the beginning of work shifts). In the example arrangement, the light experience of the crew member indeed resembles the design day (Figure 7 above).

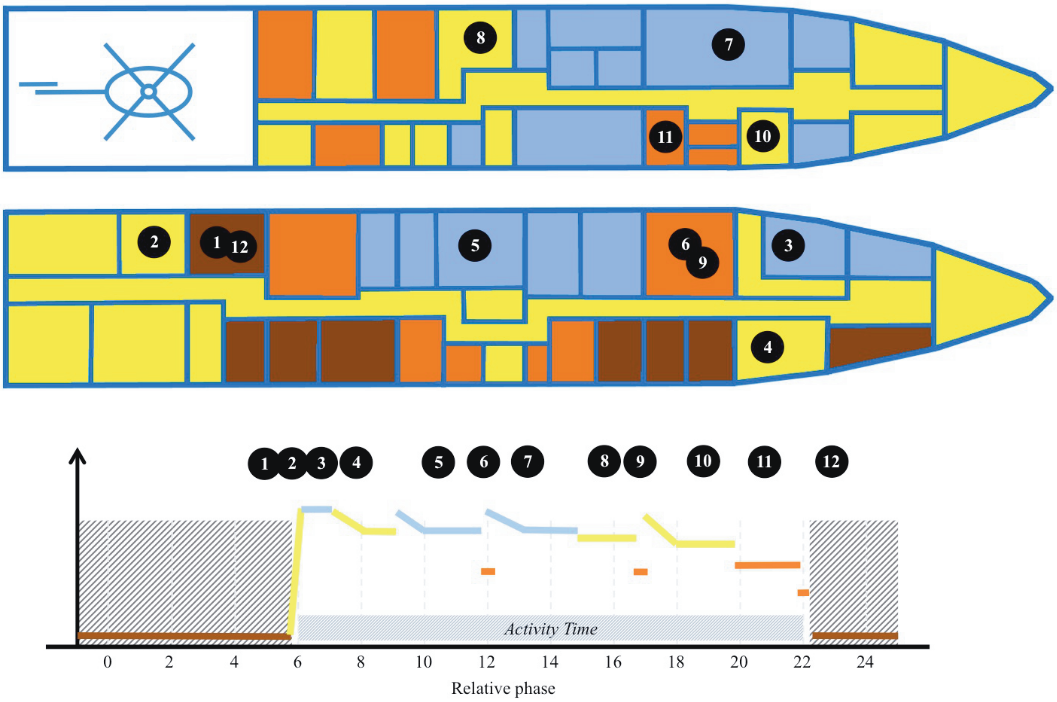

Figure 11: Example ship containing time zones: (Brown) sleeping areas; (Orange) calm down and leisure areas; (Yellow) transit or work areas; (Blue) work areas (requiring high alertness). During his day, a crew member visits positions 1 to 12 and experiences a light history as shown in the diagram.

3.2.3 A Ship with Circadian Timing

This scenario requires a ship wide light management that converts the circadian phase into a setting of spectrum, light intensity and directionality (grey marked rooms in the below example; Figure 12). Exceptions would be such rooms that, depending on local purposes, require constant lighting all the time (e.g. staircases for safety reasons). Again, a crew member, when visiting the different areas during his day would accumulate the appropriate light dose, but in this case the duty roster (relating to specific rooms) and the local light scenario are ‘disentangled’. Areas with tasks requiring high alertness are light ‘islands’: At any time of day (day or night) the affected personnel goes through transition phases and receives alertness enhancing light over the first half of the shift (Figure 13). A ‘regular’ circadian lighting example might be the ship’s canteen: Crew members start their day with an activating light scenario and, when approaching scheduled rest time, conclude with a calming one (Figure 14).

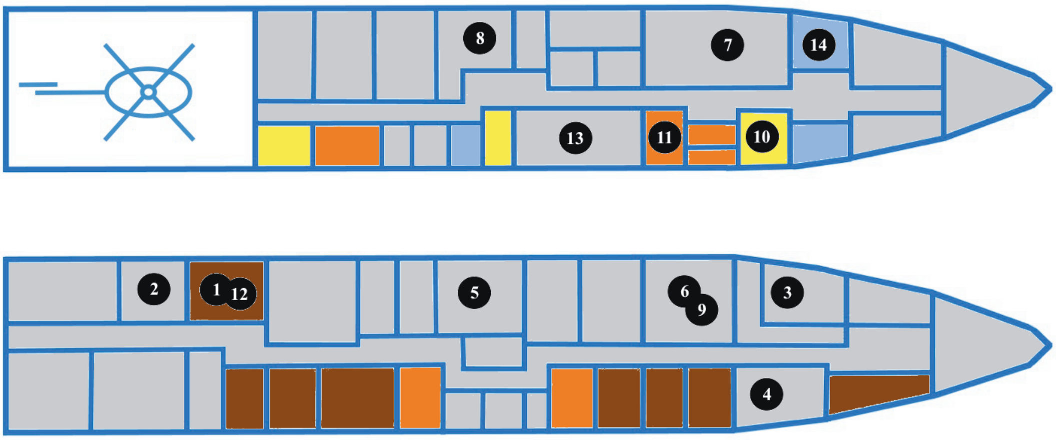

Figure 12: The ship with circadian timing has most areas under control of the dynamic light management changing the colour, intensity and direction of light. Few areas require constant lighting.

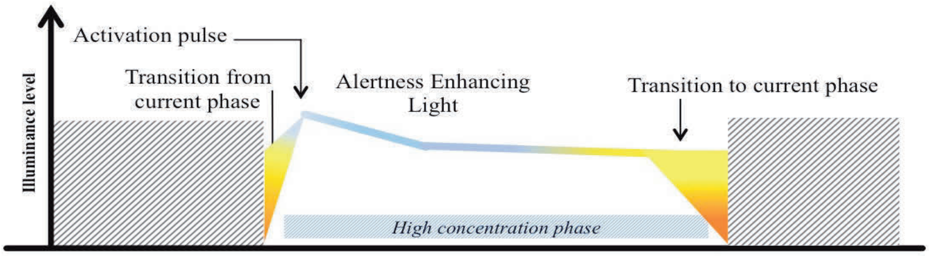

Figure 13: The light programme for areas with tasks requiring high alertness. Depending on the time of day the transition phases at the start and end may vary.

Figure 14: The on-board canteen: (left) An activating light scenario in the morning and (right) an appeasing one in the evening.

4 Visible Light Communication and other Future Trends

Electronic devices display an increasing connectivity between each other and applications exploit the 'new' degrees of freedom. More and more they will be integrated in holistic solutions. In the form of light management systems, the future has already started. A system such as the Advanced Naval Lighting System (ANLS) by LINKSrechts was developed based on the idea that a lighting platform that is open to future developments in the form of software upgrades and provides energy and information distribution simultaneously over its network. Its hardware provides all the basic functions needed to implement HCL: Programmable behaviour and centralized control of each luminaire through data transfer to and from a central unit, adjustable in intensity and colour temperature (Figure 15).

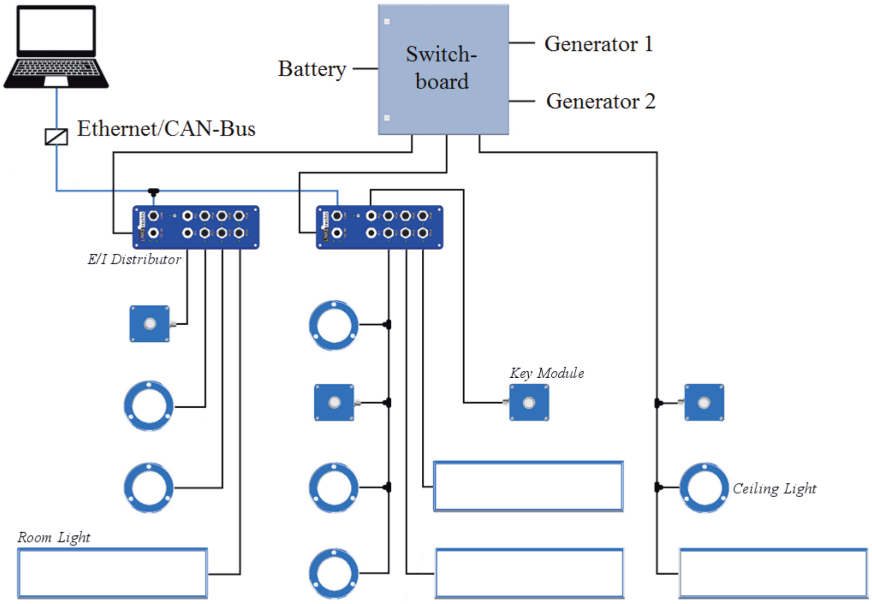

Figure 15: The ANLS is a state-of-the-art light management system for navy ships shown here in an example configuration. The general idea behind is that all components possess power and information channels. All degrees of freedom are accessible and system 'behaviour' can be pre-programmed.

http://doi.org/10.24868/issn.2631-8741.2018.022

Altogether some major developments become visible here: The 'Digitisation of Light', the 'Internet of Things', and 'Big Data'. The digitisation of light creates extreme flexibility in lighting. Ultimately this means that visible light can also be used for communication so fast that data streams are invisible to the human eye, called 'Visible Light Communication' (VLC).

4.1 Visible Light Communication

Visible Light Communication is one of the diverse optical wireless data transmission methods, in which information is transferred through visible light (375 - 750 nm wavelength). It uses LED based light sources to provide the carrier, which is modulated to broadcast signals to the open space. A LiFi enabled (mobile) device converts the light signal via a photo-detector back into an electrical signal and data are recovered from the signal. Messages can be sent to individual crew members possessing a receiver or be distributed among all personnel (Figure 17a). Such an information path might complement or circumvent onboard speaker announcements

The often used abbreviation LiFi ('Light Fidelity') for this type of optical transmission methods was coined by Haas at a TedGlobal Talk back in 2011 in resemblance to the common abbreviation 'WiFi' for (radio based) wireless local networks.

A well-known, common form of signal modulation is the pulse-position modulation (PPM) in which bits are encoded by shifting a light pulse between time slots depending on the cardinality (mathematic: number of possible elements of a set). For example - as the name suggests - a 4-PPM has four possible time slots with a pulse length of Tc ('Chip duration') within the total length of the period T. This allows two bits to be encoded by one pulse (00, 01, 10 or 11) as shown in Figure 16. Other modulation methods include combinations of phase and amplitude modulation; the use of separate colour-based channels has been reported to increase the transfer rate, which already exceeds the Mbit/s-range and in specifically prepared (short range) laboratory experiments the Gbit/s-range (Haas et al., 2016).

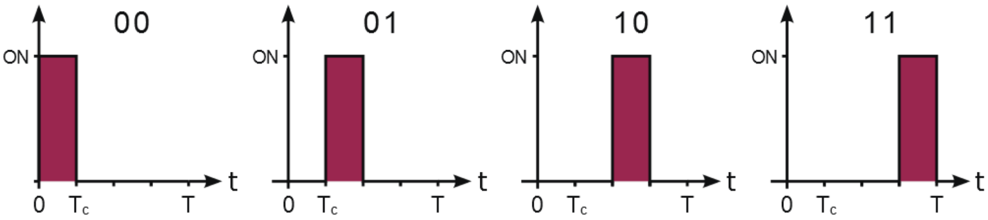

Figure 16: Information is coded in the time-shift or position of a light pulse. The duty cycle of the light pulse itself according to T determines the light intensity.

Advantages of LiFi are: Every luminaire is a modem providing a communication cell, an existing LED-based lighting infrastructure can be used, no RF-emissions occur, the light transmission spectrum is free of regulations and the frequencies are 'public domain'. For (cyber) security reasons communication can simply be shielded (Figure 17b). Without physical access to the light source potential manipulation of the data packages can be avoided even without a possible additional encryption.

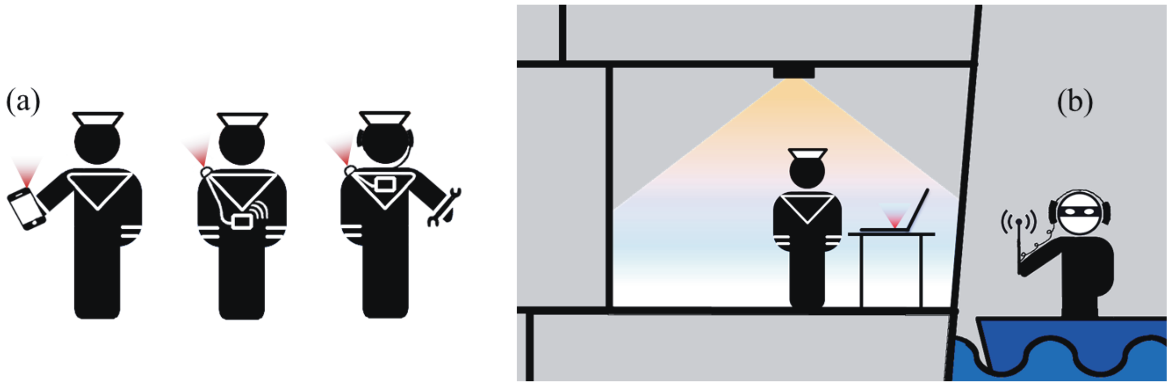

Figure 17: (a) Examples of personal equipment for LiFi communication: Hand held and wearable devices; light modems must not be hidden in pockets, a light modem as small as a button can be carried on the shoulder. (b) No eavesdropping on LiFi communication through shielding.

4.2 The Internet of useful Things

In the future data transfer will be bidirectional, each luminaire will be a network node generating its own data from connected sensors and contributing its computational abilities to the ship's local area network. The Internet-of-Things aspect is best seen in this feature. It increases the amount of information the (entire naval)

http://doi.org/10.24868/issn.2631-8741.2018.022

platform collects about itself and its crew, and it increases the repertoire of responses the platform can generate. Learning from the ‘Big Data’ will allow the machine intelligence to interpret and predict.

One objective is to shift work load to the machine and enhance the crew – even intellectually. In view of the lighting system reaching out to every spot aboard, this includes the ability of control and monitoring of each luminaire and attached devices through platform automation. Especially when crew sizes are reduced, available manpower - which would have to be used for manual inspection - is too valuable. The assistance (in addition to lighting itself) provided to an underpowered crew by an advanced lighting system can be manifold: Presence detection, localisation and identification of crew members; as a carrier of visible information it may help in reminding, instructing and guiding the crew, it may warn the crew of dangers detected by a damage monitoring system such as fire / smoke affected areas, it may help keep them away from intruders or combat areas, and in the event of an evacuation, from anywhere on the ship, the shortest route can be displayed and crew can be guided by means of moving light. Multifunctional luminaires already today can serve regular and special (colours other than white, emergency) purposes.

5 Conclusions

The promise of modern lighting is to improve life at sea by safer lighting design and distribution creating a healthier living environment. In an artificially lit environment such as a navy ship, ‘Human Centric Lighting’ addresses aspects of human biology in a way that benefits performance, subjective fitness, and well-being – ultimately a mission’s success. Implementing HCL is a logical technological advancement when making the transition towards automated light management systems.

When every luminaire, every component of the lighting system contains its own processing unit, at no additional cost, any subsequent software upgrade would incorporate the latest scientific advancements wrapped in algorithms and applications. Also, the interior lighting can be customised as desired. Regular technological updation, with customer satisfaction - what more could we wish for?

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