Fraunhofer CML

Fraunhofer Center for Maritime
Logistics and Services CML

White Paper

Increasing Maritime Situational Awareness by Augmented Reality Solutions

FOREWORD

The transport of goods by sea has always promoted and driven trade to a particular extent. In today's world, the amount of goods per unit of vessel has increased rapidly while crew numbers have been minimized. The reduction in safe manning levels is supported by the optimization of sensory information, a development that will continue as the digitalization of shipping continues.

In the past, regulatory changes in the maritime industry have often been the result of devastating disasters on or around a ship. However, such necessary changes often emerge years in advance; experts provide feedback based on their ship- and shore-based expertise and experience.

The sensory input on board ships and the possibility to use this information for safe and efficient navigation is given by technically modern systems. A major weakness here is the presentation of the different information to the user on the ship's bridge and the user-specific interaction with the systems. In order to present the large amount of helpful additional information to the user in an efficient way, future systems must be more innovative, above all more tailored to the user and more intensively networked. And they must be designed according to the valid standards.

Due to the already existing and in the future still increasing amount of sensory data, new forms of processing and user-specific presentation of the information are necessary. It is also important to ensure the reliability of the innovative systems, including secure data exchange and data security. More safety, environmental compatibility and economic efficiency can thus be achieved.

The Fraunhofer CML is active in this promising field of innovation with a wide variety of projects and has gained comprehensive knowledge and experience, and will continue to expand its research activities.

This white paper provides an overview.
I wish you many interesting insights while reading it!

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White Paper

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Content

1 Executive Summary

The technological age in which our world finds itself enables humans, through the massive support of technology, to manage ever more complex tasks. As can be seen for quite some time in manageable technologies, such as our own smartphone, the user makes less requests to the system, but rather is presented with the information that is most obvious tied to location, time and historical events. For instance, the navigation system tells us the fastest route to our workplace after we leave the front door, without us explicitly requesting this process.

The more immense the basic sensory data is, the more complex the most probable next possible information retrieval of the user to be worked out.

Especially in highly complex sensory systems that communicate in different data formats, the consideration of information output is a crucial issue for simplifying and improving user interfaces.

Navigating a ship is becoming increasingly complex as personnel on the bridge have to deal with an increasing amount of information available from different devices. This increased amount of information does not necessarily increase situational awareness (SA), which is one of the most important measures to ensure the safety of the ship and the crew.
Therefore, Fraunhofer CML is addressing compelling issues, including:

- Development of a test field, test procedure, and eva luation capability to identify situational awareness in user interfaces for bridge equipment.
- Development, testing and evaluation of a new HMI approach
- Providing ship-specific data of own ship, traffic ship and environmental data on demand or automated and presented in a modern visualization

A key technology to ensure high SA by presenting information in a more intuitive way is augmented reality (AR). It can sometimes be difficult to distinguish fact from fiction when dealing with „hyped" technologies like AR.

This whitepaper attempts to give an overview of the potential of AR in the maritime industry. The reader should know which hardware exists that can provide AR and which hardware is suitable for a specific use case. Companies which are interested in AR but are still cautious to implement it on board should understand that AR is already well established in other industries and brings real benefits.

At the end the reader should understand the fundamental principles of AR, its potentials and how it can increase SA, but also know about which pit falls to avoid when developing applications for AR.

2 Introduction

„Crew on maneuvering station" sounds the Public Announcement on board the MV „New Way". The officers and crew are preparing to enter Ningbo port. Hours ago, the pilot entered the ship via the remote interface and assisted the captain in entering the narrow fairway before nightfall and in communicating with the traffic centers and fishermen on his way.

Now the crew moves to the port shoulder and aft mooring station to connect the tugs. Chief Mate P. Hollowrath, uses his camera-based augmentation system to check the positioning of the tugs, the winch load, and the notification of the direction of the line and the pulling force of the line.

After the tugs are successfully connected, the crew prepares the mooring stations for berthing. On the bridge, the duty officer is able to provide perfect support to the captain during mooring through augmentation in his vision system, distance to the pier, water depth, vessel motion and engine values are augmented on his camera stream.

This support is given in the final process in the form of AR glasses to Captain Future in the wing so that he has the distances to the pier, the actions of the tug and the procedure on the maneuver stations in view. He safely steers his good ship between the gantries ready for unloading, and lets the crew deliver the fore and aft springs ashore.

"Goodbye and have a nice evening" calls the remote pilot, before dropping his head-mounted display ashore and disconnecting from the ship sensors.

Modern transport systems, whether in the air, on rail or on the road, have been using a wealth of sensory information for some time.
A large part of the sensor technology is installed on the transport medium itself, but there is also an increasing number of pure data connections to sensor technology that is separate from the transport medium. In both cases, the general consideration of the sensory information or the possibilities of using the information is already beyond the maximum amount of information that can be captured by humans.
Therefore, more and more tools are being used to present the information to the user in a simpler way and specifically related to the situation and environment.

This approach helps to organise the flood of sensory data. A simple example of this, besides modern navigation systems and the head-up display for cars, is the head-up display in airplanes, which is extended by some information.
These are, in general, augmentations that can display pre-processed sensory data within certain limits and with the support of possible alarm limits. The unit of measurement for transport performance in freight transport is ton-kilometers (tkm): kilometers travelled multiplied by the quantity of goods transported in tons.
In a comparison of the best-known and

Figure 1: The navigational bridge on an actual merchant ship

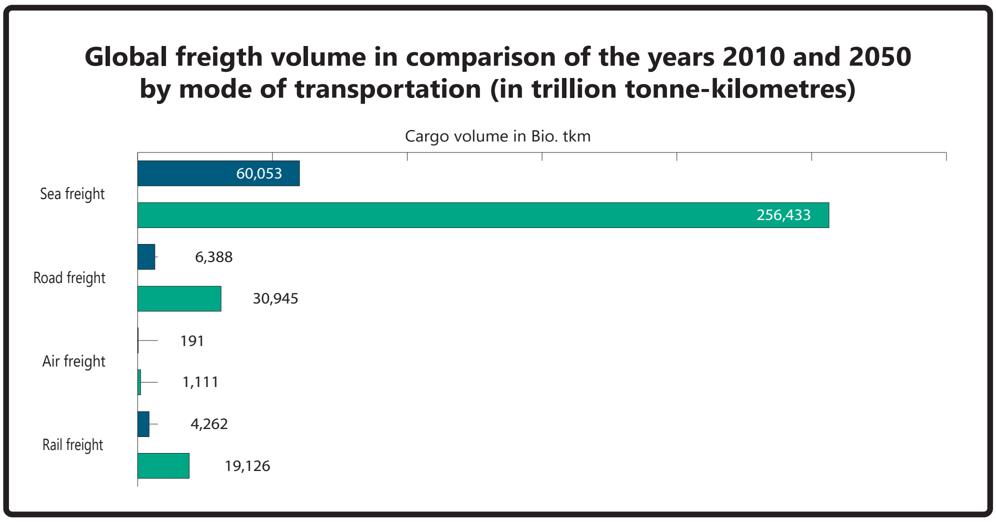


Figure 2: Global freight volume in comparison of the years 2010 and 2050 by mode of transport (in trillion ton-kilometers) [blue 2010; green 2050]. [1]

most used means of transport (Figure 2), the ship is the unbeaten leader and will remain so in the future.

As Pompey Magnus (106-84 BC), braving the strong winds, once shouted to his sailors, „Navigare necesse est, vivere non est necesse. Sed sine vita non navigamus." (Seafaring is necessary, living is not necessary. For if we are dead, we cannot navigate.), the task now is to bring the ship, the world's largest transport medium, into the digital age.

The safe and purposeful navigation of a large sea-going vessel has long ceased to be the transport of food from the Egyptian provinces to distant Rome, which is essential for survival. In our time, seafaring is an international business that must follow fixed times and is measured and judged by them. Delays, delivery problems, even minor deviations in the schedule can cause enormous delays in the fragile logistical construct.

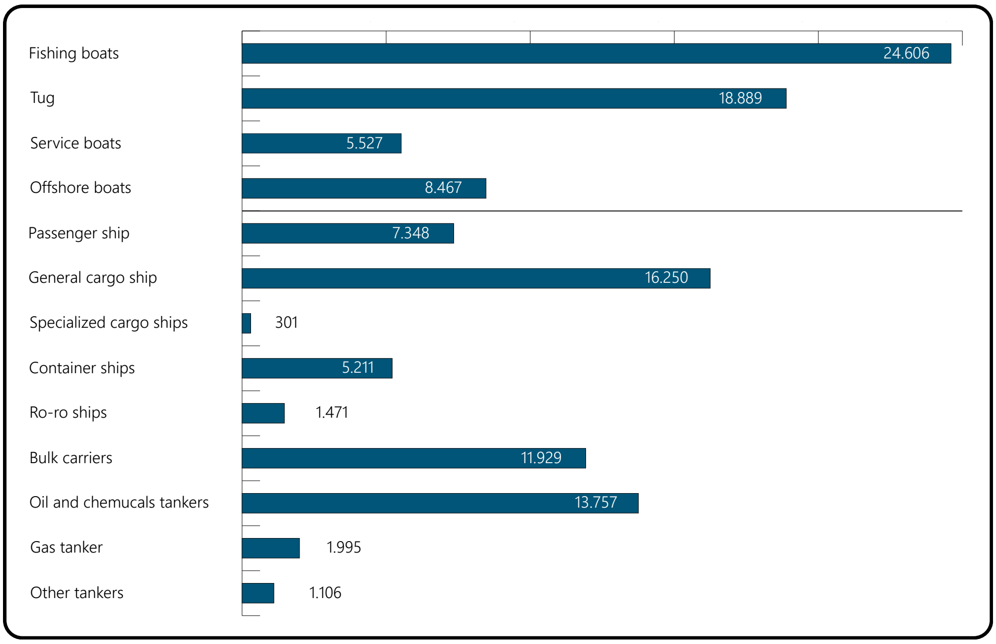
In order to orientate seafaring more safely, more consistently and also more independently of external influences in the future, the sensory data already available must be used more efficiently and presented in a more approachable way.
The world merchant fleet consists of a manageable number of units. Container

ships, which are often cited as dominant in this segment, account for just one tenth of the entire fleet. The bulkers, tankers and general cargo ships account for the lion's share (Figure 3).
In addition to the ships on high seas, local and smaller units take up a large part of the consideration in the coastal regions. Here, the fishermen and tugboat drivers stand out above all.

But whether on the high seas or in a small harbor, the ship's command's attention to the traffic situation, cargo and weather conditions always determine the safe course of the voyage and the safety of the crew.

This paper is intended to give the reader an introduction to on-board awareness, general procedures and possible future approaches and areas of application.

Figure 3: Civil market size - seagoing vessels worldwide; total number of ships - 116,857 merchant vessels; total number of ships - 59.368 [2]



3 Augmented Reality

3.1 Augmented Reality as a Subset of Mixed Reality

The basic concept of Augmented Reality (AR) is to blend computer-generated information into a human's perception of the real world (see Figure 5). Although the term can theoretically be used to describe the enhancement of any of the human senses, e.g. hearing, olfaction etc., it is commonly used to describe superimposing a person's field of view with an additional layer of visual information.
AR is an immersive technology, which means the user of an AR device perceives the additional data as situated in the physical world. The reality-virtuality continuum (Figure 4) can help to distinguish AR from other immersive technologies, like Virtual Reality (VR). While on both sides of the spectrum are the physically real world and a fully digital world, we are looking at the intermediate steps in augmented reality. The real environment shows the real world without any further augmentations. Augmented Reality means, that virtual objects are overlaid in a real-world environment.

The next step to further digitalization is augmented virtuality (AV). Real-world objects are mapped on a digital environment. With virtual reality, the complete environment is digitally represented. The umbrella term mixed reality (MR) is often used to describe both AR and AV.
AR technology substantially relies on image processing and other data sources from the real world to make sense of the environment and be able to create an immersive experience.
Although the history of AR devices reaches back until the 1960's (see [4] for an histori-

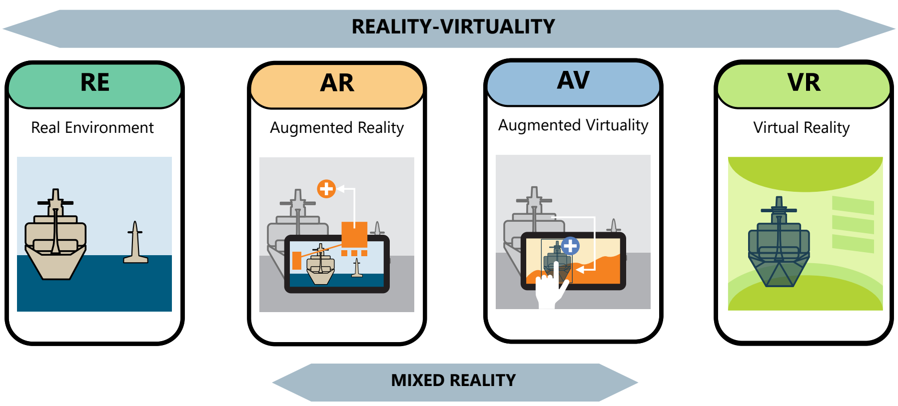
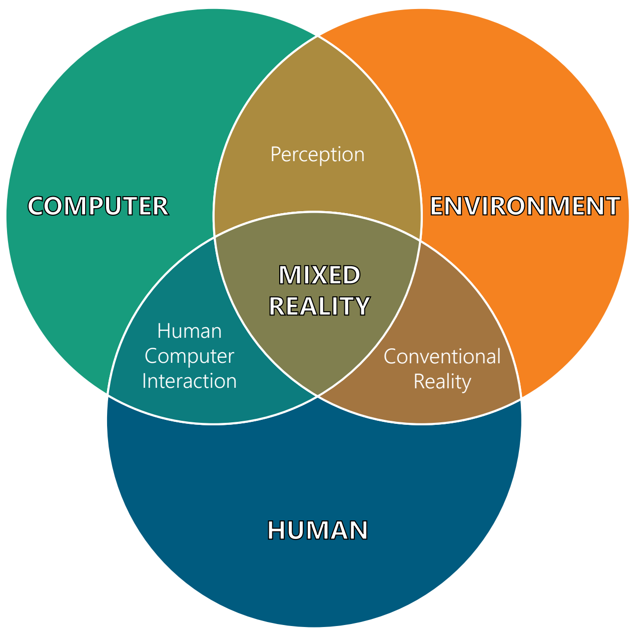


Figure 4: Reality-virtuality continuum [3]

Figure 5:
Fields of Augmented Reality



cal overview), the term gained mainstream popularity alongside VR in the last decade. Before that time AR technology was mainly developed for research or military purposes. Among the first consumer AR-hardware was the Microsoft HoloLens. Many other manufacturers followed. AR is mostly associated with head-mounted devices that use see-through displays to augment the view of the user (Figure 6), but the concept is not limited to this kind of hardware.

On the contrary, there is a wide range of AR-capable devices available.

Since the rise of the smartphone, everyone has the ability to access AR applications. Smartphones combine multiple sensors to make the use of AR possible. So, a large proportion of people have access to AR and are used to it through for example face filters.

Besides the effect of handheld-AR solutions on our daily lives, the head mounted display market itself is about to grow enormously (Figure 7), due to new technologies and precisely because the COVID 19 pandemic has changed and will continue to change

Figure 6: State-of-the-art VR and AR equipment

our daily lives and interactions with others. There are many different application possibilities to implement AR [6].

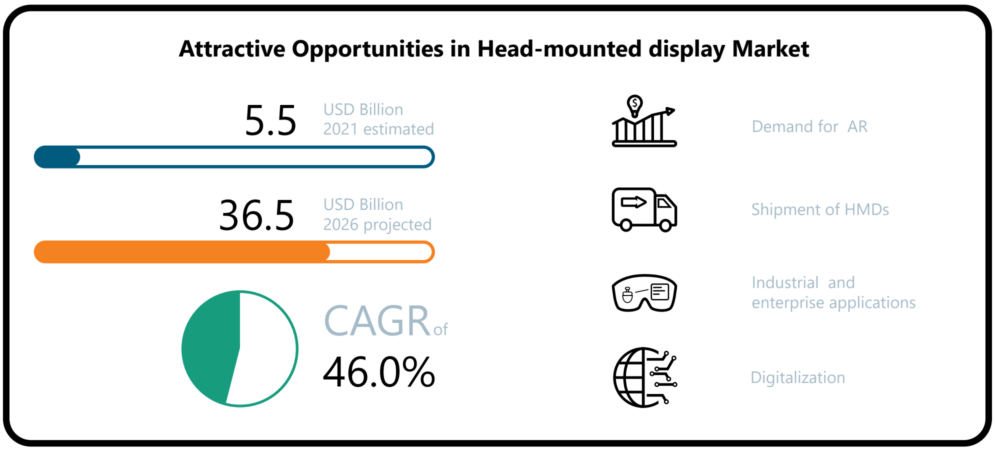


Figure 7: Head-mounted display market opportunities [5]

They can be divided into the following methods: Marker-based AR, markerless AR, location-based AR and projection-based AR.

- **Marker-based AR** uses physical image patterns to augment virtual 3D objects, text, or animation. The cameras continuously scan the position of the marker in the real environment to create the digital geometry in the correct viewpoint. When the camera is not focused, the virtual 3D object is not shown properly.
Marker-based AR works through image recognition, camera image capturing, image processing and rendering. It is easy to implement, budget-friendly and offers high accuracy.

- **Markerless AR** works the same way as Marker-based AR works, with enhancements in camera, sensors and AI algorithms. It merges the digital data with input from real-time data that are registered to a physical space. A marker is hence not needed. The mapping technology "Simultaneous Localization and Mapping Technology" (SLAM) is utilized to scan the environment and create appropriate maps to place the virtual 3D objects. The range of motion is bigger with markerless AR, compared to marker-based AR. A cue from an image or object is not needed.

- **Location-based AR** places the augmentation to a specific place by reading real-time data from smartphone cameras and combines it with the GPS-location, the digital compass and as well as the accelerometer.

- **Projection-based AR** is a stationary form of AR and utilizes projectors and a camera to augment on multiple walls. The user can freely move around the environment within a specified zone. Illusions of depth, position and orientation are created. The application is placed on a particular task space.

In the final analysis, the use of AR depends mainly on the application. This determines the required functions and input methods that are necessary. For example, whether several users are to participate in the application or only a single person. Whether you need to hold another device in your hand or not.

Starting from small hand-held devices, like mobile phones and tablets, that deliver AR-content by augmenting a live video stream and ending at large see-through displays that are built into windows and front shield of vehicles. Every type has its unique pros and cons and is aiming at specific use cases.

3.2 Applications of Augmented Reality

AR is implemented in many different business areas. A wide range of application areas are covered, and new use-cases are explored [7]. In the following sequence, application areas are explained to show the versatility of VR/AR technology.

Maintenance
In maintenance, AR can be used to guide the maintenance staff with visual information of the next steps, suggest potential fixes and point out potential trouble areas (Figure 8). Complex Equipment like car motors can be examined and maintained in a faster process. The features provided through AR free technicians from having to turn to manuals and even free the technicians' hands.

Training
In training the use of AR benefits a whole company on many different levels. In different scenarios, tasks can be tested which need trained personnel to perform certain dangerous actions. The training of these actions can be taught to untrained personnel through AR. The risk of injuring people or destroying expensive equipment is reduced to a minimum. The personnel is provided with a clear plan how to approach these scenarios and is thus more confident.

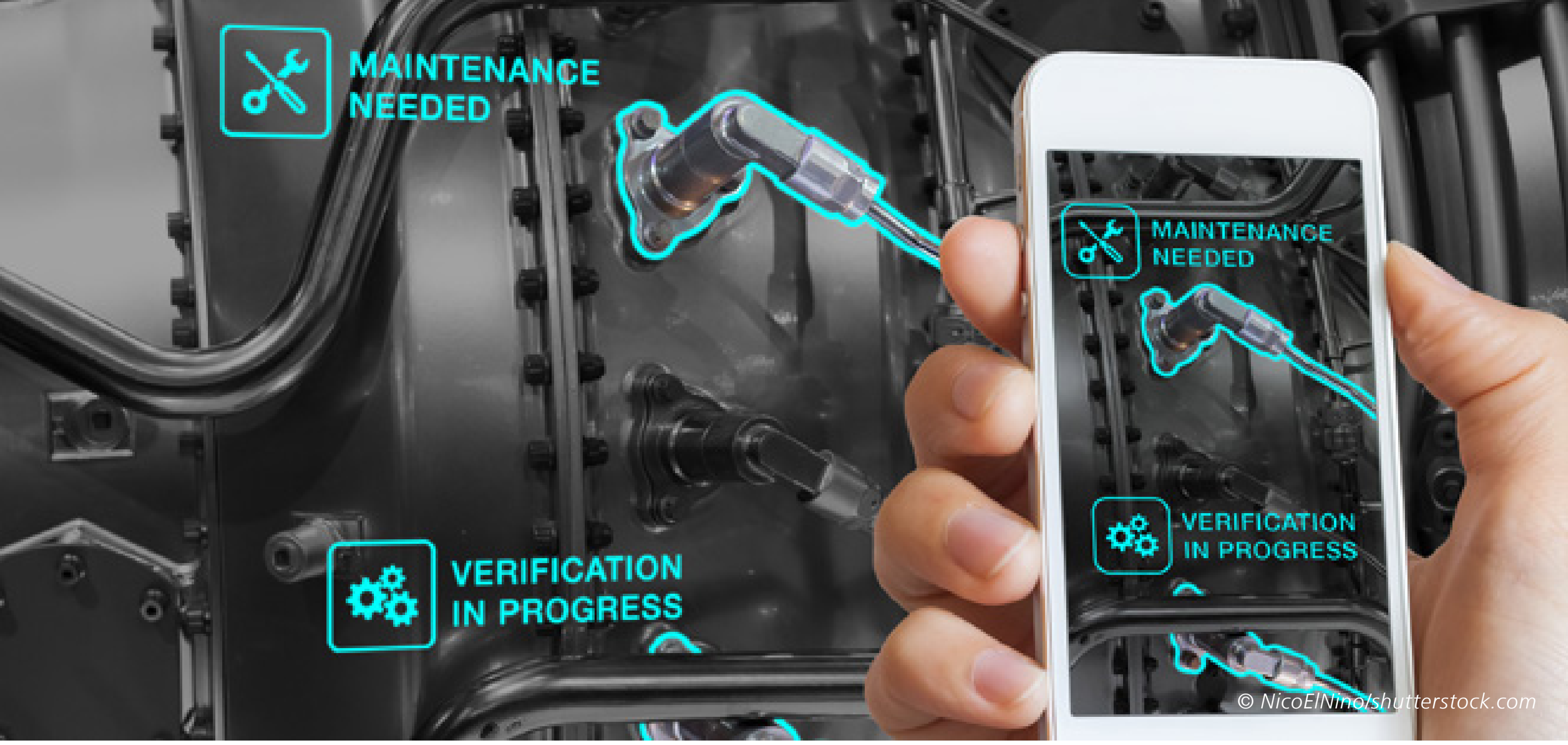


Figure 8: Example of smartphone AR for maintenance support

Modelling

- **Urban Planning**

In the planning, design and marketing of urban developments, AR helps to visualize potential problems. Between the different trades, be it electricians, sanitary engineers or road planners, there are different abstract data sets, which are not understandable for all parties. Through AR, one can combine these data sets into a combined visualization. This combination can show all stakeholders whether the available resources are sufficient or whether certain services need to be expanded. Additional simulations in the area of road traffic can reveal deficiencies in the available capacities. Changes can be designed efficiently and cost-effectively. Another big advantage is that the technology allows residents to be involved in the design process. The feedback given can be incorporated into the planning process, which ultimately promotes a sense of community.

- **Architecture and spatial planning**

Buildings built in the future benefit a lot from a digital presentation beforehand in AR. While architects used to work on the drawing board, CAD systems are now increasingly used to create designs, which can be integrated into AR. In this way, problems can be identified and improved at an early stage. in the case of larger construction projects with several decision-makers, coordination can be brought together. Revisions can thus be minimized. The use of AR also has a cultural advantage for the digitization of historic buildings.

Retail

Retail companies want to reach potential customers at home. In the past, mainly tv commercials were used for this purpose. Unlike tv advertising,
AR applications are always available. The cost of reaching potential customers is significantly lower. In addition to production costs, companies also incur broadcasting costs with conventional advertising.

Today, customers and companies benefit from the interactivity of augmented reality applications. For example, AR allows virtual furniture to be placed in the real world. Customers can see how furniture will look in their own living space before they have even bought it.
In addition, the online shop can be integrated into the AR application. This leads to a simple and interesting process for customers.

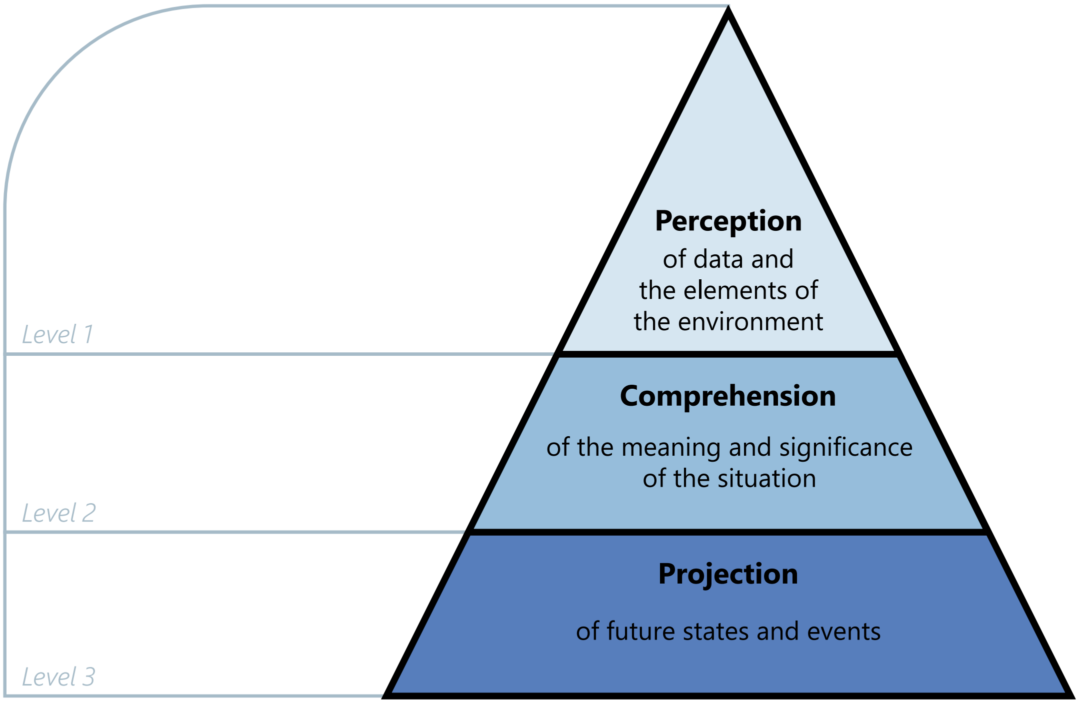


Figure 9: Stages of situational awareness [10]

3.3 Augmented Reality and Situational Awareness

Navigators have to make many important decisions in their daily work to ensure the safety of the crew and the vessel. In order to make the correct decisions, they need to perceive and understand the meaning of what is happening around them [8]. They have to form a mental picture of the current situation to be able to predict how it might develop in the future. Only in this way can their decisions be optimally adapted to the current situation.

All the above-mentioned aspects can be summarized under the term situation awareness (e.g., [9]). Situation awareness thus describes the ability to perceive important aspects of the current situation (level 1), to understand their meaning (level 2) and to predict their future state (level 3) (Figure 9). The quality of a person's situation awareness in a given situation depends on available resources and the complexity of the situation. The better a person's situation awareness, the more likely he or she will be able to make appropriate decisions [11]. Appropriate decisions, in turn, usually affect the development of a situation positively (Figure 10).

Likewise, a positive relationship between situation awareness and performance has been repeatedly shown (see [12] for a meta-analysis). On the other hand, the loss of situation awareness has been identified as an important contributing factor to accidents, both in aviation [13] and seafaring [8], as well as in other processes [14].
In general, a large proportion of accidents can be attributed to human error, which in turn is often caused by a loss of situation awareness [13].

Due to the extreme importance of the concept, it is crucial to support a person in the formation of sufficient situation awareness. In this regard, human-machine-interfaces (HMIs) come into play by providing information that supports higher levels of situation awareness [15, 11].

How well HMIs accomplish this task depends on the design of the interface. Accordingly, it has often been shown – especially in aviation – that the design of the HMI significantly affects situation awareness (e.g., [16, 17]).

Augmented Reality offers a lot of improvements to the downsides of traditional HMIs. Due to the immersive character of AR, information about an object in the environment can be placed near the corresponding physical entity.
Thereby the level of abstraction necessary when presenting the data is reduced

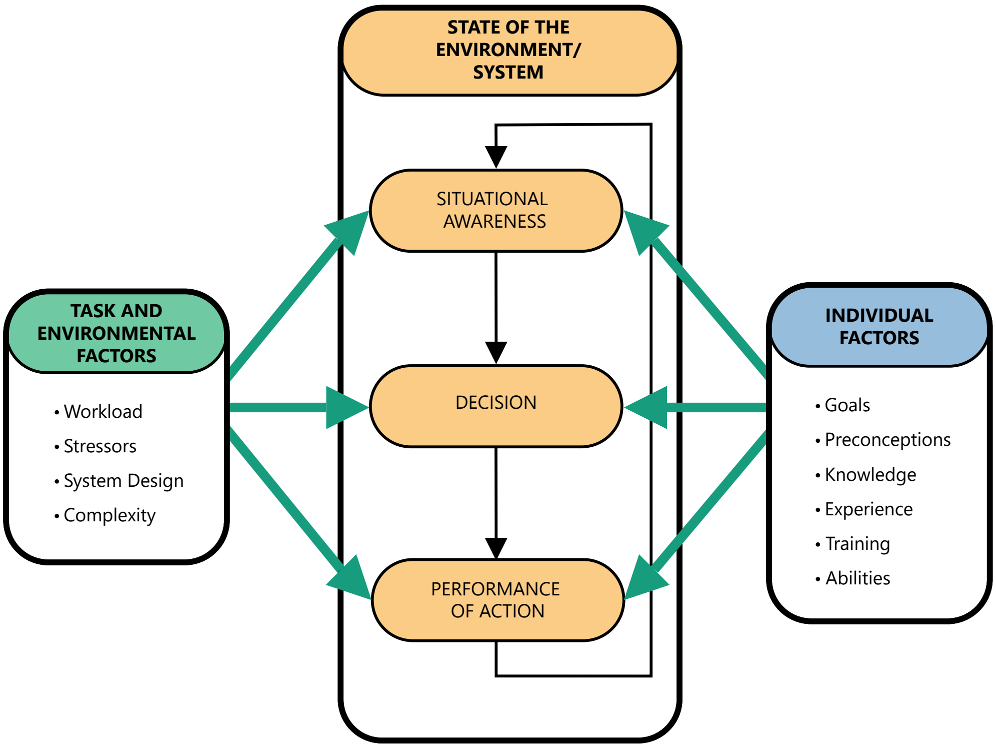


Figure 10: Simplified version of Endsley's model of SA

compared to traditional displays. When done right, this can enhance the situational awareness, because it reduces the mental workload of the participant. Working above the maximum mental workload has dramatic effects on SA [18].

Another positive effect of the capability to position information in the field of view of the user is the increased time AR lets users spend with eyes on their objects of interest in the environment. Traditionally, the user would have to split attention between observation with their own eyes and information input from other sources, e.g., displays or manuals. By presenting the important information near the object such a transition of attention would not be necessary anymore.

Consequently, AR can prevent the wasting of precious time in critical situations, because important information can be retrieved anywhere in the workspace and not only in front of a specific display. In many cases information is even spread across multiple sources, making the impact of AR even more substantial.

Furthermore, the change of the head's orientation and the adjustment of eye focus when switching between watching the environment and retrieving information from a traditional display adds cognitive load and reduces SA [19]. AR, on the other hand, can combine the data from multiple sources and thereby making the information more accessible to the user.

Augmented reality can also reduce the risk of overseeing crucial information. It can guide attention by giving visual cues to the most important objects or areas in the environment.

The advantages of AR are not limited to the first stage of SA but can also be beneficial for the second and third stage.
For example, the movement of the participant and other objects in the environment can be projected into the future and displayed in a way that gives the participant the possibility to avoid dangerous situations beforehand. Even the consequences of planned actions could be visualized before they are acted out.

Of course, to gain full advantage of AR, there are some challenges to overcome and things to consider. Until now little research was done on how information should be presented in AR. Future research should focus on how visual information should be presented to maximize awareness and minimize distraction at the same time.

Fraunhofer CML is using eye tracking in a research project to work out the effects of current interfaces of navigational devices on the situational awareness of nautical personnel (see right).

To prevent information overload of the user a filtering of the incoming data is often necessary. That's why AR depends highly on a logic in the background that is able to rank data regarding its relevance to the current situation. It should be evident that developing such an intelligence is no trivial task.

It is also important to keep in mind that the information presented in AR can only be as good as the input data. When input data, coming from external sensors for example, is flawed, the risk exists that the AR system will not be able to represent the status of the environment correctly.
That's why a dependence of the user on the information presented in AR alone, should be prevented.

235.5°
Heading
ROT
-6
Standby Pump
OFF
ON
Pilot Card
Wheelhouse Poster
Running
STOP
-20-
-40-
-60-
-80-
-100-

4 Maritime Situational Awareness

4.1 Current State of Information Processing on the Bridge

Historically, the experienced navigator has always been able to define and calculate exactly where the ship was at a certain point in time in the past and which point the ship wants to reach from there. Unfortunately, it was never possible for the navigator to define exactly where the ship is at the present time.
This fact often led to some uncertainty in the past. Since the introduction of modern positioning systems such as GPS, these problems have largely been put to the back seat. The bridge of a ship, as the location of decision-making and the clearest point on the ship, provides a good overview of the situation in the close range of up to 12 nautical miles with the output of a wide range of sensory data, and meanwhile an ever-greater insight into ranges of up to 50 nautical miles.

The bridge area (Figure 11) can be divided into 3 sub-areas. On the one hand, we have the sensory and radio-technical area in which users are provided with information visually and via audio. On the other hand, we have the nautical watch officer who, due to his training, is enabled to filter this wealth of information and adapt and use it to the situation at hand. The third part is the support provided by the seaman of the watch. This sailor, who is usually positioned in the outer area of the bridge, is capable of supporting the sensory information with visual details and acoustic signals in order to provide the officer of the watch with an ideal picture of the situation.

4.1.1 Information Processing on Board

Most of the data used on board comes from the on-board sensors mainly consisting of AIS (Automatic Identification System), GPS (Global Positioning System), Radar (radio detection and ranging) and ARPA (Automatic Radar Plotting Aid) information which are visualized on various output devices.

On many sea-going units the possibility of integration into network structures is being further developed. For this purpose, connections to Internet services such as voyage planning tools or weather routing tools are offered.

Modern networked ships also offer information support about the technical actual condition of the ship, i.e., the navigator can access certain important information about the engine, but also about ballast conditions and other important information via sensors in the engine.

The networked technology is a powerful sword, which enables the navigator to plan his decisions in advance based on the speci-

Figure 11: Current state-of-the-art navigational bridge equipment

fic actual condition of the ship and thus to implement them safely.

However, since humans themselves do not have infinite resources available for the reception of information and later assessment, the important information should be made available to them immediately and filtered.

In addition to the need to process the information, for most people the sea is an unnatural environment. This, in combination with adverse weather conditions, can have a major impact on decision making and information evaluation.

4.1.2 The Role of the Officer on Watch (OOW)

On board, depending on the type of ship, there are usually three officers in addition to the captain, who together with him form the bridge management team.
In addition to the daily tasks of the officers in their respective areas, they are on watch twice a day for four hours to lead the ship. While on watch on the bridge, the OOW is the ship's captain's representative and has overall responsibility for the safe and smooth navigation of the ship.

The Officer of the Watch (OOW) is responsible for the bridge team that assists in navigation, for ensuring that the ship complies with COLREGS and that all orders given by the master are obeyed with the utmost safety under all conditions. The three main duties of an OOW are to navigate the ship and to monitor the environment and ship itself.
Among the preceding duties of a watch officer is the safe keeping of a nautical watch while sailing between ports.

The nautical watch includes the lookout, who steers the vessel when necessary, and the watch officer, who ensures that the vessel can navigate safely and that no collision or grounding occurs.
During the watch, the OOW determines the exact position and course of the ship at specified times and as needed, using compasses and electronic and manual navigation systems.

4.1.3 The Role of the Lookout

The Convention on the International Regulations for Preventing Collisions at Sea defines mandatory rules of conduct on board ships. Among other things, it also defines the tasks of the lookout.
Rule 5 requires that „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." [20]

4.2 Disadvantages of the Current Information Processing in Context of SA

The combination of modern sensor technology with the navigation center has made it possible in recent years to determine the here and now with increasing accuracy. Despite all the positive aspects of modern information systems, it is important to probe and evaluate the flood of information and impressions, each of which is important for the situation, but also the data that is important for your own ship.

Large amounts of data are currently being visualized on a wide variety of devices, including ECDIS (Electronic Chart Display and Information System), Radar and modern GMDSS systems (Global Maritime Distress and Safety System).

As the output of information becomes richer and more detailed, it is important to provide the navigator with a way to minimize the amount of data or a way to visualize important data.

On the other hand, it is crucial to open the navigator's view towards the sea again and to detach him from the screens in order to make use of all possible means available.

4.2.1 Performing a Safe Navigational Watch

During the navigational watch, the watch officer is responsible for the protection of life at sea and on board, as well as for the general safety of the ship. Confronted with a number of national and international requirements that the OOW must comply with in order to fully meet the specifications.

In addition to the flag state and shipping company internal regulations, COLREG must be adhered to at sea as well as in port. In order to be able to meet these high targets, the watch officer has a whole range of technical aids (Figure 10) at his disposal in addition to his training and experience.

Over the years, this technical support has become more and more extensive and sophisticated. At the same time, the number of ships, their speed and, accordingly, the fluctuation of ship movements have also increased enormously, and not only at the world's bottlenecks.

In addition to data and positioning devices such as AIS and GPS, there are also major changes in the area of vessel motion visualization. The ECDIS displays on an electronic navigation chart (ENC) the own ship and the own movement, as well as the position and movement of the ships in AIS range in the environment.

Figure 12: OOW in charge of navigational watch

ECDIS may be used for navigation, but Radar in combination with ARPA shall be used primarily for collision avoidance.

These above-mentioned tools, along with compass, steering wheel and GMDSS communication to the outside, are the cornerstones of a safe navigational watch.

In addition to navigation and safe navigation activities, the OOW is also responsible for overseeing safe operations on board and in the engine.

As soon as important, non-routine work, such as a tank inspection, is due, the OOW must document and monitor this. He serves as on scene coordinator, who also coordinates all necessary steps for internal and external rescue in case of an emergency.

4.2.2 Handover of a Navigational Watch

Since the nautical watch must be kept around the clock, the practice of taking over the watch is usually done every 4 hours.

During the time of watch handover, the new OOW is provided with the necessary information on the status of the vessel with all static and dynamic data, as well as on the environmental conditions.

In addition to the tasks described in 4.2.1 information and status will be exchanged on the following information, among others.

- Vessel position, speed and course
- Traffic density
- Weather conditions and visibility
- Bridge equipment
- Miscellaneous activities on deck or in the engine room

4.2.3 Future Problems in Proper Watchkeeping and Handover of Watch

Due to the increasing amount of sensory information, it will be more problematic for the user to retrieve the necessary information in a meaningful way in the future. A solution must be found promptly in order to be able to present this flood of information in a good and usable way for the OOW. A simple solution in the form of a tool for displaying this information cannot be sufficient.

New technologies for simplified retrieval or automatic presentation of important data and alarms could be helpful here. A presentation in the context of augmented reality can be the right solution approach here. In addition to the incoming information and alarms, data could also be collected and presented to the accepting OOW for a fully comprehensive watch handover.

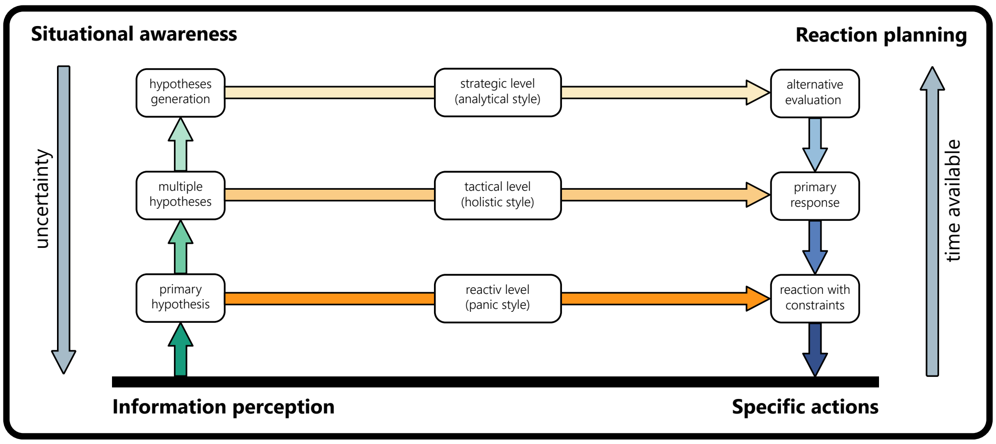
4.3 Assessment of Situational Awareness

In order to determine how interface design affects a person's situation awareness, it is necessary to be able to measure situation awareness. In the literature, many different methods for measuring situation awareness have been proposed (see e.g., [21] for an overview). In almost all methods, a person is asked to perform a task representative of the domain of interest – often by means of a simulation. During or after the task, the person is then asked to answer questions that are aimed at his or her SA.

One of the most commonly used and investigated methods is the Situation Awareness Global Assessment Technique (SAGAT, e.g., [22]), in which the subject performs a task within a simulation that is repeatedly "frozen". During the freezes, the simulation is suspended, system displays are blanked and questions about the situation are asked.

After a number of questions have been answered or a certain period of time has elapsed, the simulation continues until the next freeze occurs.
As the questions ask for information about the current situation, their answers can be objectively evaluated as either correct or incorrect, enabling the calculation of a situation awareness score.
SAGAT and SAGAT-like procedures have various advantages over other methods de-

Figure 13: Situational Awareness action map



signed to measure situation awareness (see [23, 24, 9]). Additionally, situation awareness captured by SAGAT or a SAGAT-like procedure shows the highest correlation with performance when compared to other methods [12].

In the case of situational awareness and with the important decisions involved, decisions should be made at the strategic level. The strategic level is the most analytical and involves many factors necessary to make the right decisions. Compared to the unthought reactive level, which relies on reflexes, much more thought and time must be put into the strategic level. But time is a valuable resource and is not always given. In this case, it is desirable to keep the time to an action at the strategic level as short as possible (Figure 13).

Another important point is to not overload decision-makers with information or physical tasks. Stress and fatigue have a huge negative impact on SA. This includes communication and teamwork (Figure 14).

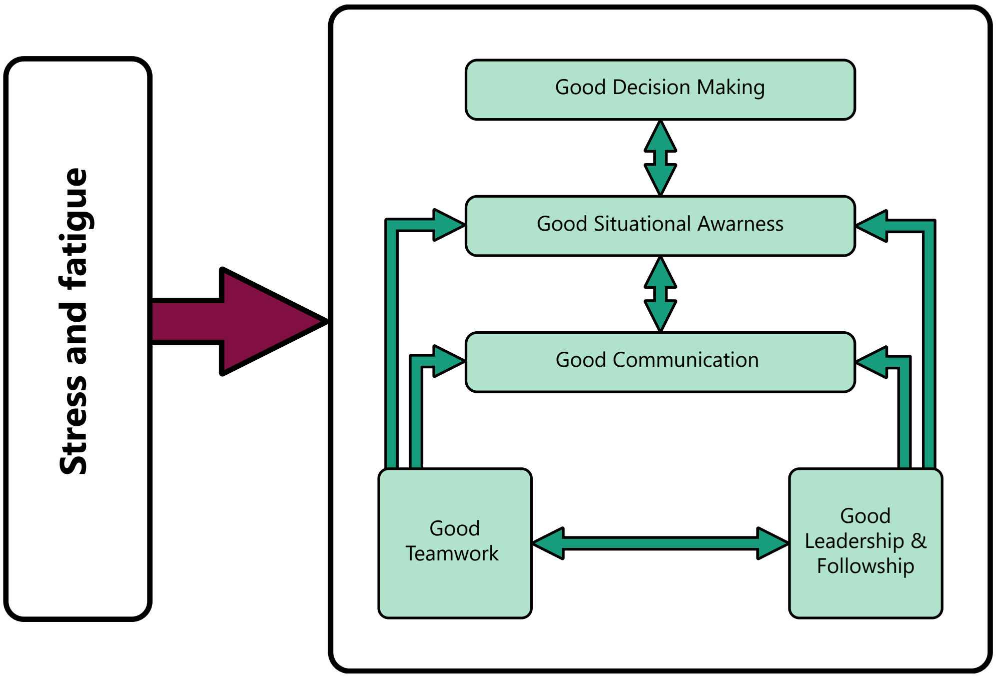


Figure 14: Decision-making cycle and negative influences

5 Augmented Reality in the Maritime Sector

The wide range of tasks and applications in the maritime sector offer rich opportunities to incorporate the already existing data and information into various AR applications. For many processes that can currently only be viewed manually or by computer, AR solutions can be found in which those responsible have a visual connection to the problem and thus gain easier access to the ideal solution for the case.

Augmented reality can be especially useful for the navigator on the bridge where the risk of information overflow is very high and the loss of situational awareness can lead to extremely dangerous situations.
Typically, the amount of information the navigator has to pay attention to is very high.

Even worse, information can come from a wide range of different devices that can take a big part of the navigator's attention. On the other hand, a high heads-up time of the navigator is regarded beneficial.
AR can solve this paradox by merging the information from different inputs and displaying it in the navigator's view. Ideally, an AR system on the bridge makes use of all its possibilities mentioned in chapter 3 to increase all levels of situational awareness. Guiding the navigator's attention to points of interest in the environment is only the first step. In combination with artificial intelligence, an AR could even give instructions for action and visualize the consequences of action beforehand.

In the following you can find a detailed description of the possible use of AR on a ship's bridge and the maritime sector in general.

5.1 Input Data

For the optimal use of AR, a lot of data is needed. The more data that can be analyzed cleanly, the more accurately the AR application can work (Figure 15).
Many data sets can be used for planned applications on ships or ship bridges.
Ship specific data would be AIS data, course data or speed data for example. Sensors such as the gyroscope can provide added value in the evaluation.
Weather data can be included. There should be no delay of the data in the optimal case. Delays can lead to incorrect graphical representation of assets.

But not only the receiving data needs to be on point. The data of the input methods must be recognizable and assignable for the application. User input options must be clearly defined.

There are multiple options for user input as the current technologies allow (Figure 17).

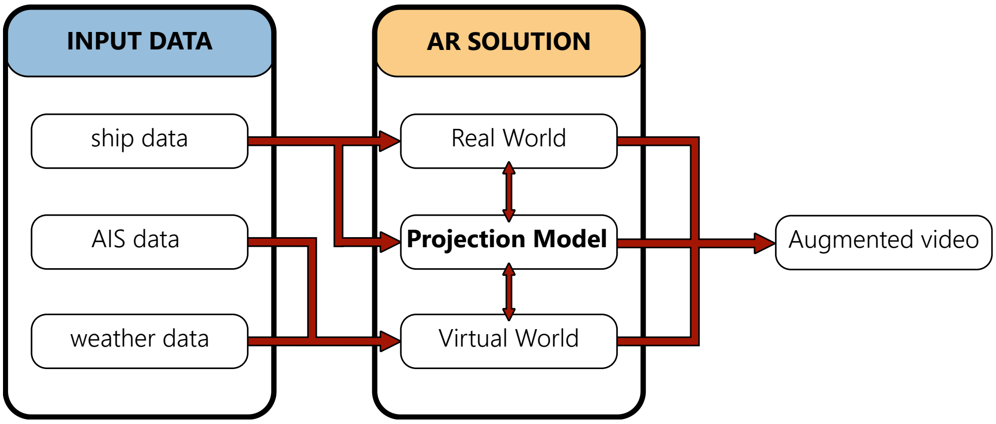


Figure 15: Components of an AR application for ships

5.1.1 Gesture Recognition

A camera embedded on the AR-headset can notice where the hands are in relation to the visual content. This so called "hand tracking" can distinguish between the different fingers, allowing inputs to be specified. Gestures can be used to navigate through functions. With hand tracking, holograms can be „touched" or „grasped".

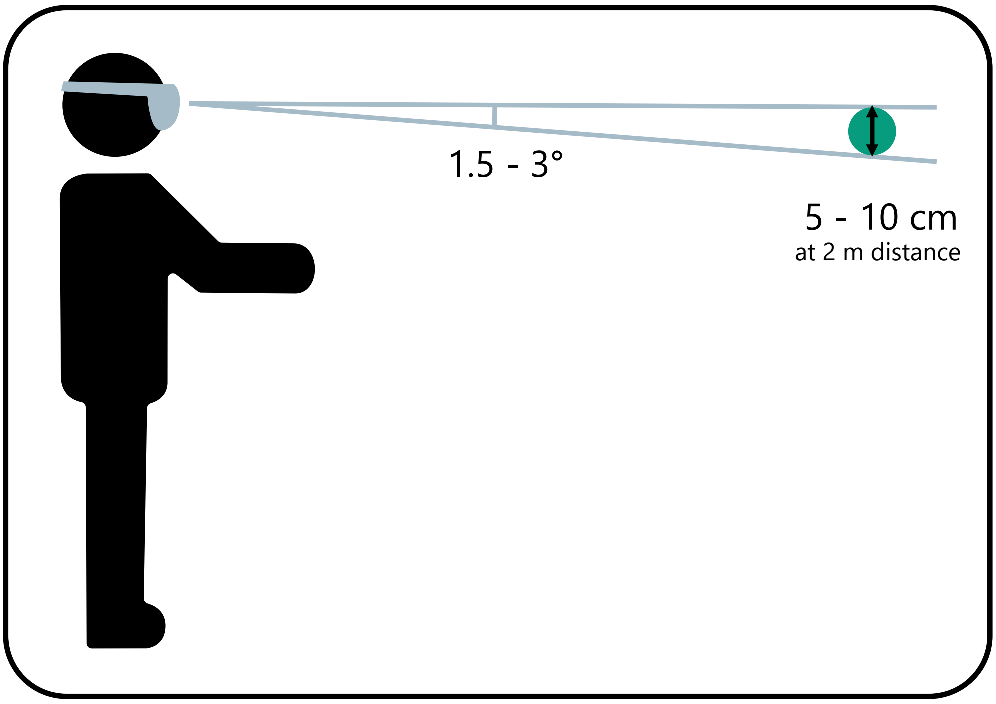
5.1.2 Eye-tracking/Gazing

The user controls the application by concentrating on certain focus points on the display. Eye-tracking in combination with head-tracking reflects the direction of the user's head and gaze.
This information can be analyzed by the program to determine which virtual objects the user is looking at (Figure 16). For eye-tracking to work accurately, each user must go through a user calibration for their eye-tracking. Eye-tracking allows to record the attention tracking, which makes it easier to evaluate and improve the user-experience in further development steps.
User research studies, training and performance monitoring, design evaluations, marketing and consumer research can be conducted with it. Eye-tracking is best used in combination with other input options to make user control more intuitive and faster.

5.1.3 Voice Command

Voice Input enables the execution of various application functions via verbal commands. Operating the system is faster and minimizes effort. The use of voice commands reduces cognitive load. it is intuitive, easy to learn and remember.
Voice input can quickly become a routine.

Figure 16: Eye-tracking accuracy deviation



The downside is that a clear pronunciation is necessary. This can cause the system to misunderstand and misinterpret input. In noisy environments, not all commands can be understood by the system. Voice control is also not suitable for work areas where silence is required.

5.1.4 Controllers

Additional equipment in the form of a controller can be used for user input. This method eliminates the need for more powerful processing compared to eye-tracking and hand-tracking but restricts the user with physical hardware.
The scope determines about the input methods. In most cases, several input methods are combined for the application purpose in order to achieve an optimal result.

5.2 Potential Use-Cases

In the context of maritime shipping, there are many potential use cases, which would

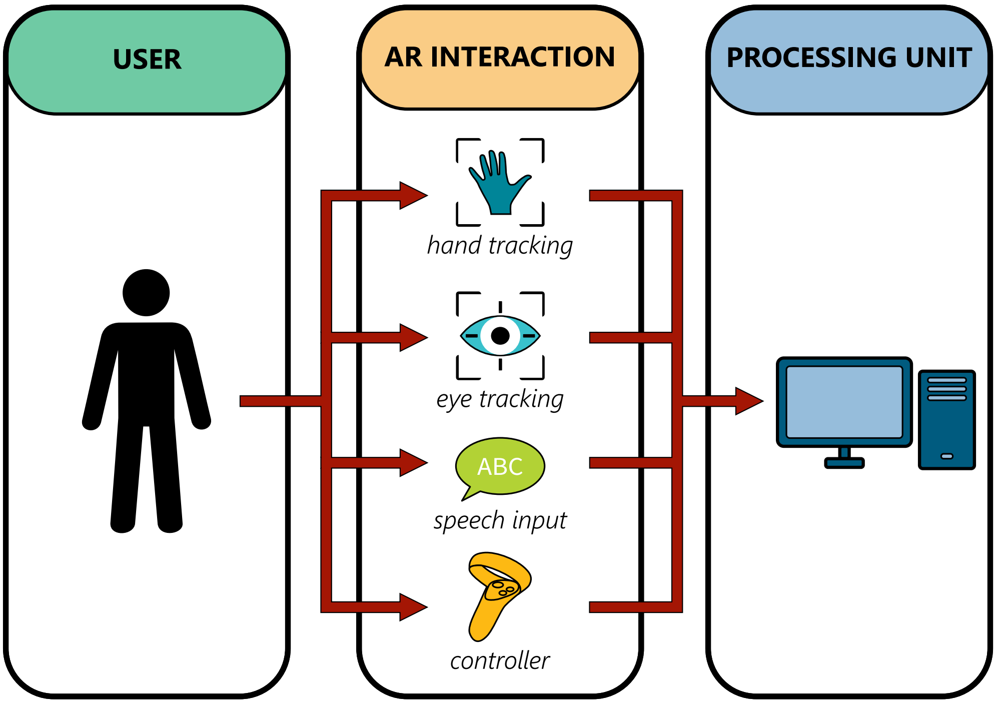


Figure 17: Interaction types for AR applications

benefit situational awareness. Both on board and ashore, important time can be saved by selecting and displaying relevant sensor information.

The land-based information processing system can usually offer a higher number of personnel and a broader distribution of tasks. In many TSS centers, however, the responsibility for monitoring a larger and usually complex traffic area, the so-called traffic separation scheme, is very high. Observing maneuvers of many different ships, assessing possible dangerous situations in a preventive manner and, in case of doubt, intervening with the right advice are demanding tasks.

In order to withstand the pressure and not to miss any important information, it is important to use the information provided as effectively as possible.
Similar to the ship, a diverse portfolio of sensor information is used here as well. Ra-

Figure 18: Types of visual representation in AR.

dar towers can be found in many land-based centers. This information is completed with AIS information and thus offers a rich set of data.

Here, too, the correct use of sensor information, the analysis of the output data and the user's interpretation are crucial for the effectiveness of such systems.

5.2.1 Supporting the Navigator
Augmented reality can be a powerful tool for the navigator to make sense of the great amount of data available on the ship's bridge and therefore increasing SA. For usage on the navigational bridge of a ship the AR system should allow the users to move around unrestricted and have their hands free for their actual tasks at any time. Hence, head-mounted displays (HMDs) are the most reasonable choice for this use case (Figure 19).

The ways in which (HMD-) AR can present information to the navigator can be classified in one of the following categories:

1. Show Location-independent Information in the View of the Navigator.

Displaying information about the status of the ship (e.g. SOG, COG, HDG etc.) in AR offers the advantage of providing this information independent of the navigator's position on the bridge. The navigator can therefore spend much more time observing the environment ("heads-up time") and safe precious time in time critical situations.

2. Marking Objects in the Environment with a Symbol.

The risk to oversee import objects in the surrounding can be decreased by marking them in AR with a symbol. Such objects could be other ships, buoys, ports, and many more. The objects cannot only be marked but also additional information can be shown. In the example of another ship this can be any information that helps the navigator to estimate the future position of the ship to avoid collisions. Marking important objects reduces the workload on the navigator, because it is not necessary to translate information from ECDIS or Radar to positions in the three-dimensional world. The input data needed for recognising objects in the environment is AIS or input from computer vision algorithms that recognize unidentified objects in a video stream.

3. Projections on the Water Surface can Mark Areas in the Environment.

When dealing with objects in the environment with a large extent, like hazard areas, working solely with symbols might not be the best solution. In such cases, the best

solution would be to superimpose the whole area with a semi-transparent overlay. An additional projection of the course of the own ship can help the navigator to decide if a change of course is needed to avoid such areas.
Examples for the three types of visual representation in AR can be seen in Figure 18.

In shipping, the use of augmented reality in combination with machine learning can lead to the development of systems that improve situational awareness by, for example, detecting ahead of time other vessels that do not have the usual communication programs of modern mariners.

Existing systems use alarm systems to control pre-set control ranges and to notify the user if the values fall below certain values.

An example is the CPA of an acquired contact that falls below the minimum value specified by the user.

After notification by the system,

- the user must evaluate the information displayed and compare it with the real situation.

- In order to make a safe decision on how to proceed, the planned maneuver must be evaluated with other objects and dangerous situations in the close range.

- If a possible successful maneuver is found, the action is started.

- Before but also during the maneuvers the way of the maneuver execution is crucial for the success of the same.

Thus, according to COLREGs, the maneuvers should be executed in time and thoroughly. The implementation is directly dependent on time. The later the maneuver is performed, the more drastically it must be performed.

The work steps listed here represent a common scenario in the watch of a nautical officer and represent one of the greatest potential hazards in modern shipping.
Due to the modern sensor systems and technology on seagoing vessels, situations can be assessed well and safely.

However, this assessment is incumbent on the human being and therefore his level of knowledge and training, but also in direct dependence on his daily form.

It is crucial to provide the navigator with a view of the dangerous situations in the surroundings by supporting modern information filter systems, to support and evaluate possible maneuvers already in the process, to assess and visualize them for the navigator.

Figure 19: Use of AR on a Shiphandling Simulator Bridge

For example, small fishing boats can be captured by camera systems and shown on a display by programs that combine AR and machine learning. In combination with infrared cameras, this can also increase awareness during night-time driving.

On the other hand, ships with state-of-the-art communication interfaces can be augmented with all important information on AR glasses or a screen. The transferred information of the speed and direction of the ship can be visualized at which point in time the ships will be in the future.
This would be an additional help to avoid collisions.

The interaction with other data sources as well as a visually enhanced presentation can be used by crews on board, but also by shore personnel to plan and execute trips more effectively. A used voyage planning tool in combination with a weather optimization tool can be visualized in a virtual viewing system. This can be used in the time planning for passing critical areas on the voyage, but also for sensitizing the crew in advance.

Prior recordings from the cameras can create a database of different ship routes. By using 360-degree cameras, a ship's captain can prepare for the voyage by analyzing previously recorded voyages in time-lapse in VR. Danger zones can be highlighted in the video footage. This allows the captain to prepare better. This use case is particularly helpful for routes that are new to the captain. Video footage for voyages to unknown and hectic ports can lead to better preparation. A better preparation leads to more situational awareness.

Another use case is in the area of the port. The arrival and departure of the ship can provide additional useful information through augmentation. For example, in combination with LiDAR sensors, distances to other structures can be made clear. This makes it possible to perform fine maneuvers more safely. For this purpose, an innovative visualization system could support the crew, the pilot, but also the shore operators (Figure 20).

It would be conceivable to display specific ship information in the field of view related to interactions (e.g., ship in the process of unloading, ship in motion, pilot on arrival, pilot notifications, tugboat messages, etc.).

5.2.2 Further Potential Use-Cases in the Maritime Sector

Besides the importance on the ship's bridge, the use of new visualization methods is also conceivable for solving existing problems and workflows in other areas of the ship and ashore.

- A support for the planning of lashing points of special project cargo;

- Support of an employee in the engine room or in an enclosed space, on the one hand for monitoring and on the other hand as support for the solution of necessary tasks;

- Or as a test environment for the development and evaluation of innovations or for the optimization of operational processes

5.2.2.1 Cargo Control

Modern visualization systems can facilitate the crew's work, not only for navigation. For example, AR during the loading process can be used to visualize important information about the cargo in order to improve the logistical process and to improve accuracy and efficiency.
Furthermore, the use of safety-relevant information during so-called enclosed space inspections or during berthing and unberthing maneuvers is conceivable. Containers could be equipped with QR codes that can be read via AR glasses.

All important information about the contents of the container would be augmented directly onto the glasses.

This would allow the user to access the following information:

- The content of the container

- Travel Route/Destination

- Temperature

A misplacement of IMDG cargo can be identified. In the event of a spill of harmful substances, the user can be directly shown how to behave. Safety instructions can be augmented onto the AR glasses, leading to an increase in situational awareness.

Visualization of the different fill levels on the ship can simplify control.

5.2.2.2 Maintenance

As mentioned in the previous chapter, the use of AR methods to increase situational awareness also has a value-adding function in maintenance.

When machines in the ship fail, maintenance can be greatly simplified by using AR. Users get step-by-step instructions on how to repair the machines.
By using the AR glasses, they always have both hands free and are released from having to use a manual. In addition to the work steps, it can be visualized what the user must pay special attention to. In some

cases, for example, it could be the leakage of oil during a certain work step.

This allows all preparations to be made quickly and appropriately. The use of AR can facilitate following pipelines.
Especially in areas where many pipes run together or past each other, it is difficult to keep track.
During maintenance work on the pipelines, they can be tracked more easily. In another application, it would be possible to perform maintenance remotely. In this case, the user wears AR glasses on board and is guided by a technician on land. This would be helpful for both maintenance work and inspections. The technician can mark and highlight objects and locations directly in the view of the user on board.
This makes it easier to overcome technical and language barriers. Maintenance can always be performed with the help of a professional.

5.2.2.3 Creating Test Environments

On the one hand, the ships are in service to deliver goods and thus bound to strict schedules; on the other hand, early involvement is often undesirable or extremely difficult to realize due to exemptions granted by the class and the flag state. Another advantage of shore-based testing is the direct feedback from the navigator to intensify the surveys and findings as needed.

When you want to implement software, you want to make sure that it is fully functional at launch. As mentioned in the previous chapter, test environments help to develop better systems and applications.
By specifically creating a test environment, one can create certain situations. In these situations, it is possible to virtually test and evaluate methods. It is also possible to create specific situations in which the user must perform certain maneuvers to react appropriately in the situation. Latency times play a subordinate role in a purely virtual test environment. Sensor data can be simulated on request. Data sets are available without delay and can be changed at any time.

Similar processes are currently applied, especially with regard to the maritime market [28], in the context of which large-scale test campaigns are hardly feasible in the first phases of development on real ships.

5.3 Using VR for AR-Prototyping

Under optimal circumstances, the required data can be retrieved at any time through suitable interfaces. A flawless communication between system would benefit the user experience.

The truth is that there are not always suitable interfaces for all systems. Older ships are not always technically up to date.

Figure 20: Steering a Tug remotely in mixed reality RoboTug project

Linking old and new systems is time-consuming and intensive. Even if lossless communication between different systems is possible, legal regulations may not always allow it.
Since the applications for AR listed here are based on the linking of different data sets, be it sensor data or ship data, a suitable real-life test environment cannot be created in a fast way without major inconvenience. Different parties would have to make their resources available for a real implementation.

The development of a unifying system and the merging of data can be very costly and time-consuming, only to see in the worst case that a research attempt does not bear fruit.
A whole simulated test environment would get rid of this problem. In a virtual environment, records can be created, deleted or modified at any time. Data can be transferred without loss. Interference signals are not present. Every little detail could be changed in an instant. For this purpose, the use and implementation of Virtual Reality (VR) can be the solution.

A VR environment can be created using game-engines and head-mounted displays (HMD). The use of HMDs allows the participants to perceive and interact with the digital world. HMD reflect the orientation of the person in the virtual world.

The user is immersively integrated into the simulation and can influence the virtual world through his actions.
A VR environment can serve as an experi-

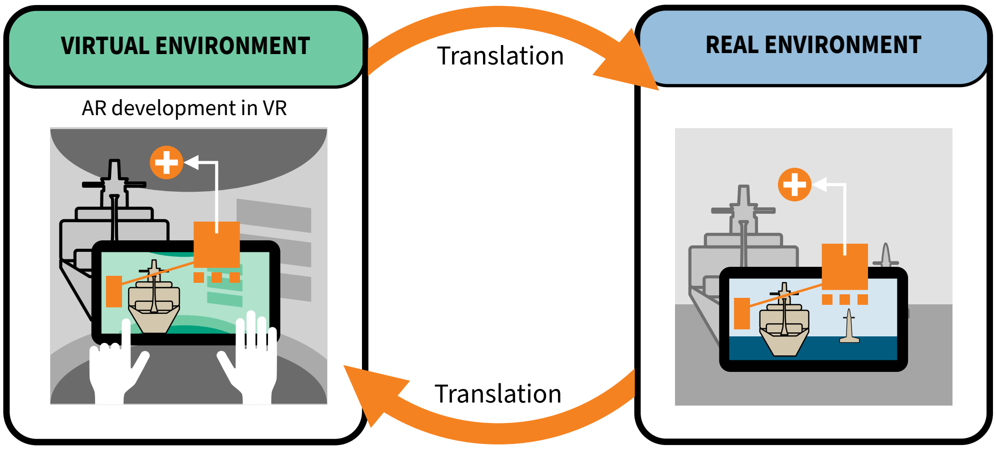


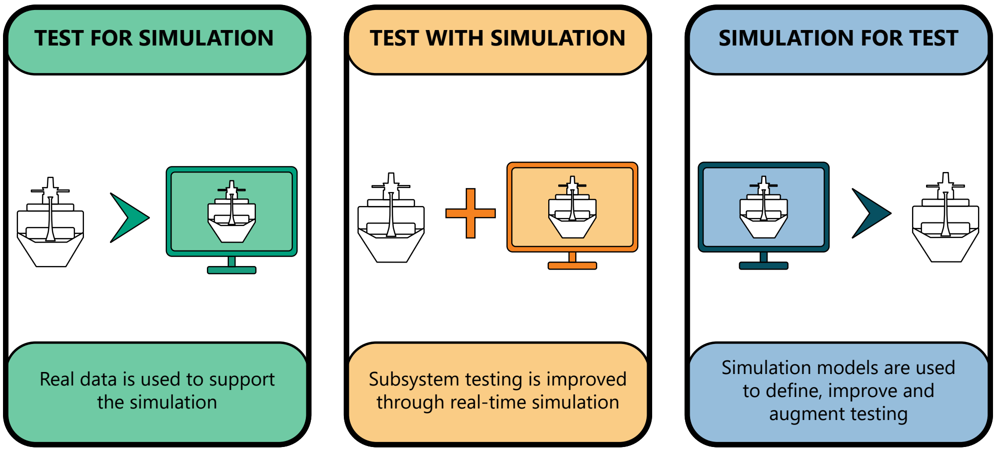
Figure 21: Cycle of testing and developing maritime applications

mental bridge between a research idea and an actual implementation with AR in real life (Figure 21). A development process must be clearly defined for this overarching work. In this case the use of model-based development or MBD in short is suitable.

With these modification options, VR is the perfect tool for training and simulating.

Solution approaches for the use of AR can thus be fine-tuned.

Figure 22: Different types of model-based development



The advantages are, on the one hand, the simple simulation of a test environment and, on the other hand, all kinds of the simulated data are directly available (Figure 22). Short-term changes and adjustments can be tested directly from the workroom. With the use of VR, many different specific scenarios can be created for testing purposes. Parameters could be set for your own ship, as well for other ships and how many of them are represented in a scenario. Different weather conditions could impact the scenario.

If the methods developed are satisfactory in the virtual environment, implementation in the real world can be considered.

Figure 23 shows that the testing is separated from the implementation in the development cycle.
The testing is done in VR, which mimics the real world. The implementation in AR can follow after a suitable solution in VR has been found.
The basic software architecture can be adopted. This results in little additional work.

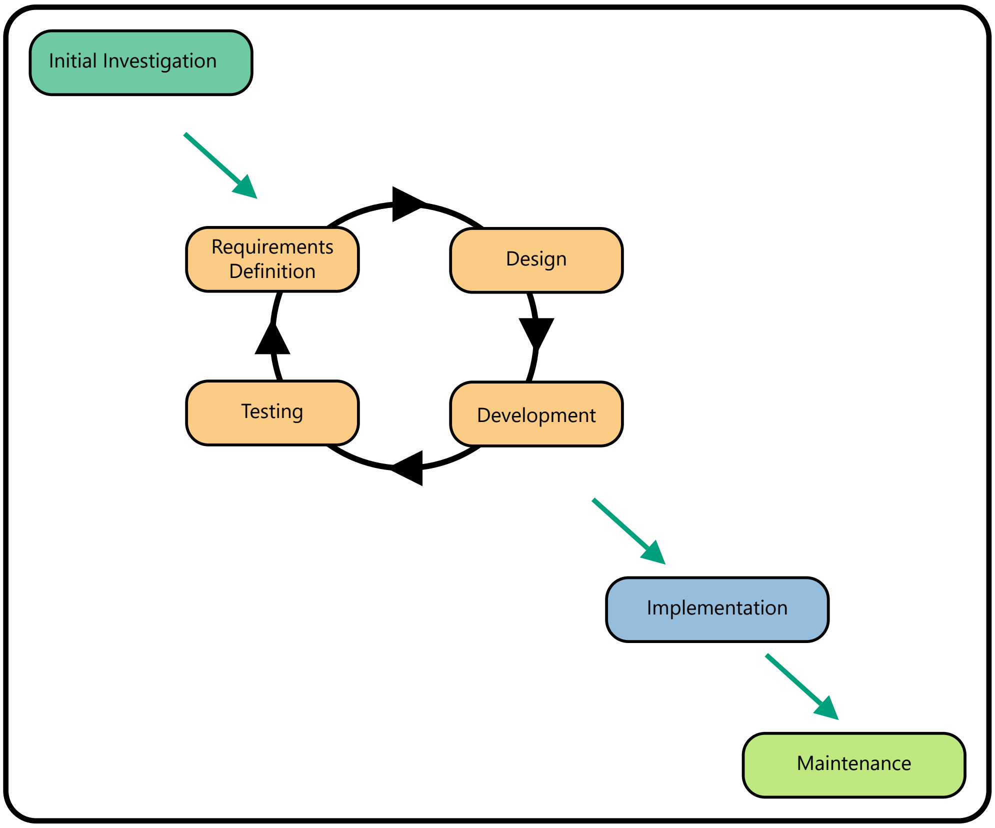


Figure 23: Production steps of an application

The various examples given here provide only a small glimpse of possible future applications for this innovative technology.

The maritime market, despite its limitations in connectivity from sea-going vessels to land, offers the ideal breeding ground for future developments. Especially in the area of monitoring, safety and security, there are already countless possibilities to make life and work processes on board safer and thus support seafarers.

Fraunhofer CML sees this as one of its priority tasks in the coming years.

6 Opportunities for Cooperation with Fraunhofer CML

Fraunhofer CML helps companies to close the gap between theoretical advances in maritime digitalization and practical application of data-based methods. The process of integrating AR into real-world applications involves a high degree of customization. Fraunhofer CML has substantial experience in building AR solutions for data-based predictions and decision support systems in maritime logistics from proof-of-concept to implementation.
Solutions are specifically tailored to the requirements of the maritime industry and individually adapted to the needs of the customer. In detail Fraunhofer CML focused within the last year on implementations of remote control and assistance systems for the maritime market.

Fraunhofer CML's RoboTug Project [29] is one of the first ventures to successfully steer a tugboat through mixed reality.

The objective of the project RoboTug is the development of a remote-controlled tugboat to increase safety and efficiency in ship navigation in ports.

At the Fraunhofer CML, special attention was paid in the project to achieving realistic situational awareness in the remote-control environment.
Through augmented reality visualization, the real tug's field of view is enhanced by virtual displays that provide the personnel with the necessary information to safely implement maneuvers from a shore station.
For this purpose, innovative approaches of augmented reality were applied using the latest findings, among others from the gaming industry.

In addition, the Fraunhofer CML is currently working on a conceptual study for the design of maritime HMIs for ship guidance.

This is being done in 3 interconnected activities.

- Creation of a simulation-based test environment and test methodology for the investigation and evaluation of maritime HMI.
- Research, development and evaluation of the implementation of innovative HMIs for route monitoring and collision avoidance and derivation of best practices for navigation systems based on classical screen technology.
- Investigation of novel interaction and visualization technologies such as augmented or virtual reality for shore-based monitoring and decision-making systems.

The Fraunhofer CML has the opportunity to draw on the available resources of the Fraunhofer Gesellschaft within the framework of the project work.
In addition to a wide range of international and national contacts, these are of course also the specialist areas of the various Fraunhofer institutes. In particular, but not exclusively, in the BEYOND project, the competences of the Fraunhofer FKIE with regard to the development, implementation and evaluation of HMIs are used.

The human factor is of central importance to the work carried out at Fraunhofer FKIE. Research focuses on developing effective and efficient human-machine systems, with the focus on a task and situation dependent presentation of information on navigational displays.

In cooperation with the Memorial University of Newfoundland, a novel approach to assess the situational awareness of navigational officers based on SAGAT was developed. With this approach, tailored for the maritime sector, it is possible to evaluate, whether modern ship bridge designs can enhance the situational awareness of watch-keeping officers.

Fraunhofer FKIE is part of the German delegation to IMO NCSR, whose work led to the development of regulations such as the performance standards for integrated navigation systems MSC.252(83) focusing on task-oriented system design or the IMO performance standards for the presentation of navigation-related information on shipborne navigational displays MSC.191(79).

Fraunhofer CML partners with Novia University of Applied Sciences and Aboa Mare in Turku, Finland in a joint research platform called "Fraunhofer Innovation Platform for Smart Shipping at Novia University of Applied Science", short FIP-S2@Novia. The joint research addresses smart systems in navigation as well as maritime digitalization.
It benefits from Novia's wide expertise in maritime training and simulation, including research in VR based training. Future joint research projects will aim, among other, to develop and transfer novel VR applications in maritime navigation and training into practice.

In other projects, Fraunhofer CML builds modern mixed reality solutions into ship bridges to increase situational awareness.

Maritime safety, the situational awareness of nautical shipping personnel and the improved presentation of the situation picture to increase safety on board and life at sea are core topics of the Fraunhofer CML.

For this purpose, one team is dedicated to the sensory fusion of existing sensor technology, extended by a 360° camera system and the presentation of this gained information on board of seagoing units. In a second part, the already presented information is extended by augmentations and additional information using machine learning algorithms.

The information that can be presented in this way, whether in ahead of, beside or astern of one's own ship, should enable the navigator to optimize his reaction time and to focus on the corresponding critical contacts.

The combination of the sensory collected and the detected information in the ML area are augmented in the visual range of the navigator. The solution of a, in this case, mixed reality solution that we are advising is being tested by various navigators.

The BEYOND project mentioned above will create the necessary evaluation conditions for this and the knowledge gained from this will enable future navigators to use more intuitive user interfaces that will increase their situational awareness and the safety of all those involved in shipping to a high degree.

Fraunhofer CML proved in past projects, is proving in existing projects and will in future projects its drive for progress in the maritime sector.
The technology of displaying information in the user's field of view, within a screen of an output device, as well as a networking of land-based and ship-based sensors and their information linkage will be the next essential step to increase safety and productivity at sea and on land.

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