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Ad-hoc Situational Awareness by Optical Sensors in a Research Port Maritime Environment, Approved Networking and Sensor Fusion Technologies

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Abstract

The Research Port provides a physical experimental test bed for sensor data fusion, communication technology and data stream analysis tools to increase safety by observation and monitoring of the maritime environment. New e-navigation technologies can be tested using real industry products. This can reduce time-to-market and help to standardize new technologies.
Optical sensor technology can provide a situational and marine environmental assessment of waterways for (i) online detection of relevant situations, (ii) collection of data for further analysis and (iii) reuse of data, e.g., for training or testing of assistant systems. The setup has to consider maintainability, flexibility and extensibility of the Research Port components. This means that new use cases and applications within the existing Research Port infrastructure can be easily developed and extended by installing new sensors, actuators, and / or software components. Furthermore, the system supports reliable remote communication between onshore and offshore participants.
A series of in situ experiments at the Research Port and within the maritime environment were performed, representing applications and scenarios to demonstrate the capability for the proposed system framework and design.

Keywords: situational awareness, optical sensors, wireless network, data fusion, maritime test bed

Introduction

Modern information and communication technologies can be exploited to improve the efficiency and safety of maritime traffic. A working group of the NMNT (German National Masterplan Maritime Technologies) states in their position paper that “Efficient maritime transport reduces the environmental impact by reducing pollutant emissions, preventive accident prevention protects against incidents with disastrous consequences for persons, environment and economy [1]”.
By means of cooperative synergies between technical supportive systems situational awareness can be provided for users to enable decision support and reduce workload (compare the automotive sector). *Therefore our intention is to provide information about safety-critical and environmentally hazardous situations, to assess and avoid the latter.*
The design of such new supportive e-navigation systems requires methods and tools for testing and simulation approaches. They need to be based on grounding experiments, to prove the concept, reduce development costs and enable the assignment of new system-engineering methods [2]. Therefore the eMaritime Integrated Reference Platform (eMIR) enfolds tools for simulation and experimental physical test beds for new approaches and technologies for e-navigation and by this also includes logistics and hinterland connection, sustainable and compatible use of marine ecosystems and other shore side aspects. All these test beds extend simulation environments into the real world and offer services for grounding experiments. These services include a reference waterway, a research port, a mobile bridge system and a Vessel Traffic Services (VTS) system [3].
In the following we focus on the Research Port as one of these experimental platforms. We, will explore optical sensor systems cameras (visual light, infrared) and LIDAR (Light Detection And Ranging) systems. Video sensors are widely used for civil surveillance,

providing a situational picture [4]. In addition optical remote sensing became increasingly important for, in this case maritime, environmental observations [5, 6, 7].
To increase spatial coverage of the sensors in a dynamic environment with moving objects in the waterway, and to increase the reliability of the system and make affords for synoptical information redundancy it is much more advisable to use geographically distributed sensors than one single sensor.
As a consequence of the demand to set up distributed sensors in real word study areas there are challenges for the complete sensor framework. Among others [8], we need to address distributed deployment, extensibility for large area sensor networks, video stream and information transmission, remote access between onshore and offshore participants, central system administration, uniform open data interface and networked synchronized operation.

This leads to the following research question: How it is possible to use independent flexible sensor systems with open interfaces in a maritime environment, for the generation of distributed situational awareness by sensor fusion technology?

The approach of this paper is divided as follows: in the section *System architecture*, we describe the framework for sensor-based research and development platforms [9, 10] and the implementation of the data stream architecture [11], which are based on our prior elaborations. Further on, we present the system setup of the physical experimental test bed, followed by the section *Results and discussion.* Therein onshore and offshore field experiments within the Research Port and the maritime environment are presented. We provide a proof of concept for the following applications for the test bed:
(i) online detection of relevant situations, (ii) collection of data for further analysis and (iii) reuse of data.
Finally, we conclude the work and provide a short outlook in the end section.

System Architecture

As mentioned in the introduction the system architecture needs to support distributed installations for sensor based research.
Figure 1 shows an overview of the main components that the system architecture needs to implement. Solid lines denote the data flow, dashed lines the control flow. Before sensor data is used within the architecture, it should be processed by quality and validation components that can e.g. check whether the illumination is sufficient for a certain camera system. Succeeding quality and validation, raw data can be led to *modules* and or stored in archives (as required for later replay of data). Often, applications do not need raw data streams but some kind of processing (e.g., filtering or selection of data), which is provided by processing modules. On the top layer, *applications* (like dashboards for situational awareness or decision support systems) receive data from the system. They specified their data needs to the *adaptive configuration* component that makes sure that the needed data is routed by the *communication* component to the application. The results of such modules can not only be sent directly to applications, but they are also integrated into the so-called *world model*. This component is key for situational awareness: live data updates from sensors are correlated with pre-knowledge (semantics) about the observed situation, like map data or mobility models of detected objects. If a history of data needs to be kept, live world model data can be stored in *archives*. On the bottom layer, several distributed *sensor systems* should be supported; if a real-world field test should be enriched by simulated data, we also need interfaces to simulation modules.
To implement this architecture, we set up a data stream management system (DSMS) to cope with the additional requirements, namely the management of distributed sensors, the storage and replay functions, the handling of high volume video streams, and the interfaces to simulation components.
Similar to a data base management system (DBMS), a DSMS provides a high-level interface to specify the applications information need. In a DBMS, this is typically realized by a

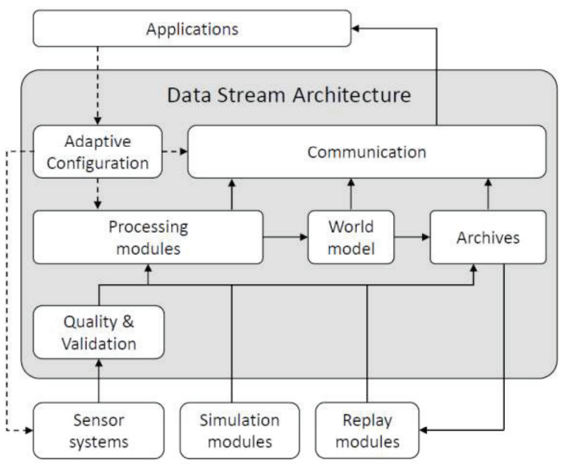

Fig. 1: Components of the Architecture showing information and control / data flow with actors, environment (real / simulated), sensor, world model, communication and application layer connections.

SQL query API, where the application sends a one-time query and gets the results. Since the applications in the test bed need an on-going data stream, it would need to query the framework in a high frequency, leading to high data volumes not only on the data flow, but also on the control flow (the queries).
Therefore, a DSMS distinguish for continuous queries [12]. Here, the query is sent only once to the data management system, and results are continuously sent to the application whenever they are available (similar to the publish-subscribe paradigm, sometimes also referred as event-driven architecture).
Sensor data fusion can happen at several semantic levels which require different effort by the user. The simplest form of sensor data fusion is temporal visual alignment. Here, data from several sensors is visualized on the same screen in different frames. The only processing provided by the system is a temporal synchronization.
The next level of sensor fusion would be at feature level. A feature is a measurable data fact, e.g., the temperature of the water at a given position. If several sensors provide this information, a user could define an aggregation function to fuse several temperature values into one. Such aggregations could easily be defined using standard data stream queries.
The highest provided level is sensor fusion at the world model level. To enable distributed situational awareness between participants in the architecture, world models can be generated. A global model fuses, cleanses and filters raw sensor data from all available data sources to obtain high semantic levels relevant for situation detection and system decision. If there is no sufficient communication link available, local world models are generated using only those sensors available to one node. Subscribers then can access these models via network connections.

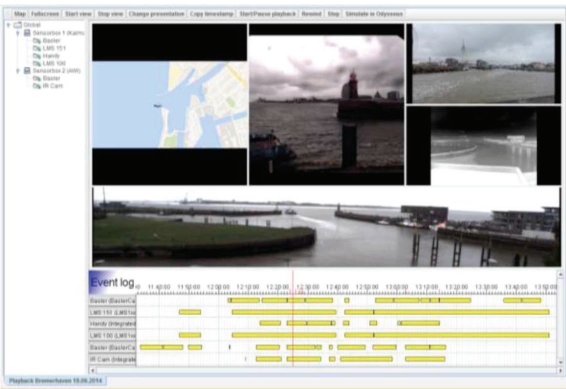

Fig. 2: Graphical user interface of the data stream Admin Client Application in replay mode with covered scenes from the Research Port Bremerhaven, Germany.

Our set-up is based on the DSMS framework Odysseus[1], developed by the University of Oldenburg; in general, the system architecture could also be implemented using other DSMS systems. However, since Odysseus was designed as an extensible framework for data stream management systems, our requirements could be realized with a reasonable effort [13, 14].
To disburden the user from formulating the queries, we developed a data stream Admin Client application. Using a graphical user interface (illustrated in Fig. 2), the user can register new sensors to the system, start and stop data archiving, or replay stored data. Also the visual alignment of sensor data can easily be realized by the general Admin Client Application.

System setup

The setup consists of a sensor network communicating with an internet-accessible base station, providing a flexible system for sensor data recording, processing and access. The nodes of the sensor network, the mobile sensor boxes, can easily be placed at different locations, where they establish a multi-hop Wi-Fi-link to the base box (Fig. 3, top). Different kinds of sensors can be attached to each box. Base sensors and protocol handlers are: visual (VIS) camera (Basler, C++ SDK), infrared (IR) -camera (Optris, SDK), LIDAR scanner (SICK, TCP/IP) and GPS (Navilock, USB/RS232, NMEA0183 [15]).
The sensor boxes may also be placed on a vessel, where they record and store data until these findings can be transferred to the base box or a mobile box with connection to the base box. It also provides remote access to the stored data and the research port infrastructure via Wi-Fi to an admin client in the harbor area, or via internet. The mobile sensor boxes provide an internal power supply, Ethernet, USB interface, Wi-Fi access and a LAN hub, packaged in a weather-proof box for mobile outdoor sensor measurements (illustrated in Fig. 3, bottom).
Multiple self-sufficient boxes form a sensor network using Wi-Fi bridges, directional antennas (Nanobeam M5 AC 500) or wired Ethernet to overcome long communication distances to the base box. Sensor data recording, processing and access is realized using the high-volume data stream architecture. In the context of research on e-navigation, high-volume data streams often are provided from moving objects such as vessels, or come from ad-hoc sensor configurations for a specific experiment which can be flexibly handled with this framework.

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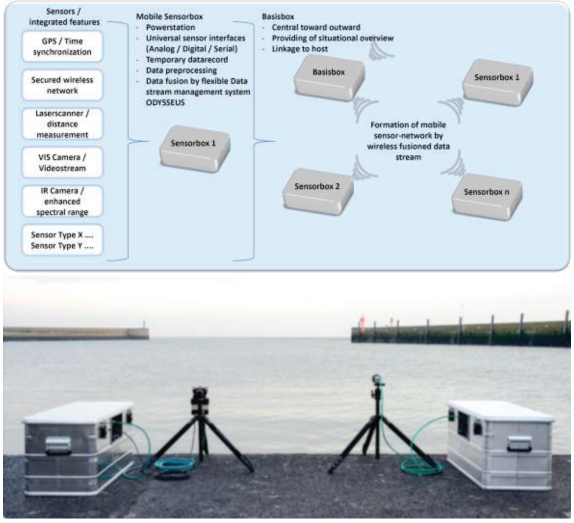

Fig. 3: Top: Exemplary structure of a single mobile sensor system with sensors and integrated features (left) and schematic of a multi-hop Wi-Fi network formed by distributed sensor systems (right). Bottom: Self-sufficient mobile sensor systems nodes with LIDAR scanner (left) and visual camera (right) in front of a port entry.

The architecture for the framework offers a unified sensor access and data fusion approach which allows a flexible use of the platform, supporting different video sensor sources such as DirectShow video devices (integrated laptop cameras, USB cameras etc.), Basler high-resolution 4k visual (wavelength range 300 nm – 1050 nm, VIS) cameras (equipped inter alia with wide angle lenses, transmission range 400nm – 700 nm) and Optris PI450 infrared (7.5 µm – 13 µm band, IR) cameras with 38° x 29° prime lens. Further detailed information of the architectures system integration and periphery sensor devices is presented in [11].

Results and discussion

The proceeding sections described the operating principles and development of the uniform flexible optical sensor systems at technical level. Therefore technical tests were preceded successfully for ad hoc networking connectivity, sensor data stream scripts and central administration of the distributed sensor systems. Wireless high volume data transfer for long distance onshore – offshore communication was tested in the field over a range of 1000 m via 5 GHz WLAN beam bridge (Nanobeam M5 AC 500) up to 300 Mbps for video streaming suitability. Specifications of antennas promise further

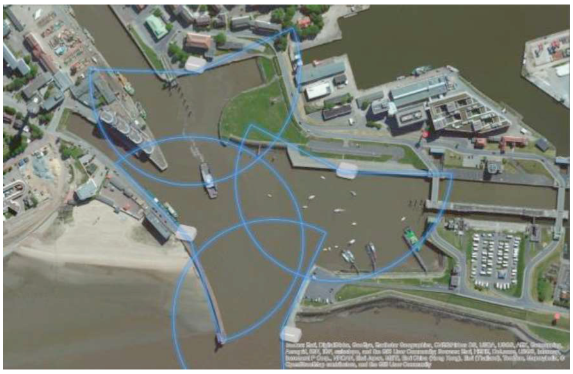

Fig. 4: Overview of the covered area (highlighted by semi-circles) from distributed sensor systems in the port Bremerhaven, Geestemündung. Ferry terminals, (at the top), a double lock with berths (at the right) and the port entry (at the bottom).

ranges up to 5000 m, with a limitation of reception angle. Furthermore, special check-ups of visual- and infrared camera lenses were performed in the optical laboratory.

In the following, we introduce applications for the purposes of the physical test bed and present results from the optical sensor system setup in the Research Port maritime environment.
For field experiments we used the port in Bremerhaven, Geestemündung as a Research Port. The port is located in Bremerhaven, Germany (53° 32.133' N, 8° 34.667' E). With its highly frequented ferry terminals, berths at the entry to a double lock and the upstream waterway it is a suitable study area for the geographically distributed optical sensor systems. Up to four observation stations were temporally equipped with the self-sufficient sensor systems, attached to VIS-cameras, LIDAR scanners and one IR-camera (highlighted in blue in Fig. 4), where these establish a multi-hop Wi-Fi-link (illustrated in Fig. 3, top), covering the study area.

(i) Online detection of relevant situations

As the optical sensor system is designed to provide distributed optical sensor information for participants over a canalized data stream interface it is obvious to use these for the detection of relevant situations. These may occur due to obscure information management, e.g. insufficient dissemination or incorrect appraise for a local threat [16] and can cause safety-critical and environmentally hazardous situations. Therefore the sensor system information could be used to support

for situational awareness to assess and avoid such situations.
In the context for e-Maritime environment applications we present in the following scenarios for the online detection of relevant situations. To that end we inspect various berthing and critical situation maneuvers, person overboard situations and the remote sensing of sea surface temperature which is related to the environmentally circumstances and the state of the upper ocean.

- **Berthing assistance**

Berthing assistance tests were been performed with stationary onshore and mobile offshore placed sensor systems. By the onshore demonstration, the video and laser scanner data were wirelessly streamed between the stationary sensor systems from the Research Port towards research vessel (RV) Heincke and vice versa, the latter utilizing a vessel-based LTE connected mobile sensor system. Furthermore a forward looking camera and LIDAR scanner was placed at the bow deck at the RV and connected to the sensor system for a mobile survey. The fused data of the sensor systems was then streamed wirelessly and displayed by the Admin Client Application (introduced in Fig. 2) on the bridge of the research vessel, supporting situational awareness for locking, port income and berthing maneuvers.

Another assistance approach for berthing maneuver was performed with a mobile sensor system, installed on RV Senckenberg. Two LIDAR scanners were placed near midship on port side and starboard side, both at working deck level (about 1 m above the sea surface). This position offers an unobstructed horizontal scanning angle of 180 ° and a detection range of 20 meter radius for coverage of the vessel sides / board walls, illustrated in Fig. 5. Two visual cameras, equipped with wide angle lenses, were additionally positioned at bridge level, aligned to the field of view of the LIDAR scanners. They provided the corresponding live video picture of the measured LIDAR structures and supplemented the LIDAR distance map. This is also to enhance the assessment of the LIDAR information, because the horizontal scanning range requires a corresponding object height above the sea surface level for coverage structures, which is, especially during high tide, not preexisting in tide-dependent berthing facility.

- **Person overboard situation**

A life-endangering situation can happen if a person gets overboard. Especially seafarer or dock laborers are exposed to this danger. To demonstrate the support for locating a person in sea water, a controlled test (without danger to life) with shipboard carried sensors was carried out.
The objective of this exercise was to create a safety-critical situation in which a person is floating in water. We used infrared (thermal) camera information to locate and track the object. Emulating a person, a safety buoy with a water filled container (initial temperature 40 °C) was prepared and lowered into the (4.5 °C) cold water (performed in February; Fig.6). Subsequently, the vessel went away up to 400 meter from the lifebuoy. Meanwhile the temperature difference of the warm body became smaller over time due to heat exchange with ambient water.
An automatic detection by a measuring grid of 3x3 pixels of the maximum temperature in the thermal image was proven by this observation for about 150 meter object distance within the first 10 minutes for the warm body. The measuring grid falls short of 3x3 pixels for the tracked object and in addition waves masked the tracked object at distances above 150 meter according to the vessel carried camera perspective and prime lens of the recognition approach.

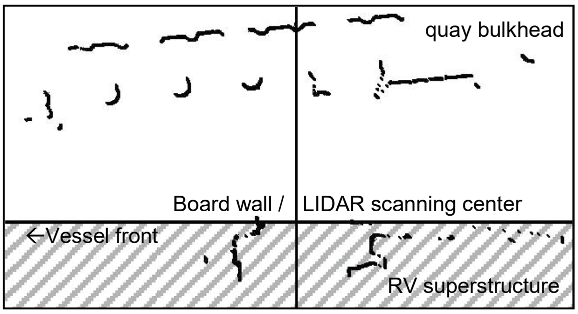

Fig. 5: Shipborne LIDAR scanner, data while berthing maneuver on starboard side.

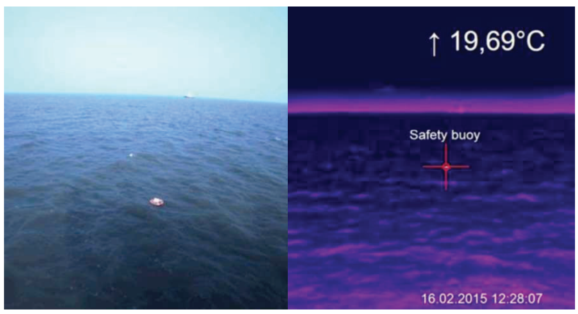

Fig. 6: Person overboard exercise, inspected by shipborne optical sensors. Visual- (left) and infrared-pseudocolor- (right) video image.

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- **Remote sensing of the sea surface temperature (SST)**

Optical sensor systems are highly relevant as a remote sensing tool for maritime environmental research and operational applications [17]. Thermal infrared imagery provides the sea surface temperature (SST) which varies with environmental conditions (e.g. according to the daily cycle of heating by the sun) and is also an important variable in air-sea interactions. The passive sensing method derives information from surface infrared emissivity and (if applied on water) from a layer only several micrometers thick.
The infrared emissivity factor of sea water derived for nadir view observations is in the range of 0.96 – 0.99 at wavelengths relevant to thermal remote sensing (the corresponding ideal Planck (black body) emitted radiance is 1.00) hence can be considered high [18]. Monitoring of the sea surface temperature is intimately related to surfactants, surface films, thermal convection or pollution impacts [19], corresponding to the state of the upper ocean.
The usage of a sensor system, equipped with a PI 450 infrared camera (7.5 µm – 13 µm band), enables us to exploit the spatio-temporal variation of the SST.

As part of a demonstration in the Research Port area, a stationary system was positioned looking to port entry, waterways and a ferry terminal, as illustrated in Fig. 7 (top). Region of interests (ROI) were predefined in the radiometric video image to the sea surface port area and also to the waterway area where vessels pass by, illustrated in Fig. 7 (bottom). The measurement output resulted in the mean temperature of the ROI (emissivity factor 0.96). The temporal temperature profile of the port ROI (black graph) showed the heating treatment of the sea surface by the sun occurring at cloudless sky conditions within 20 minutes (here in June). The waterway ROI provided the temporal temperature profile of mean temperature (blue graph) within this area. Herein we found, additionally to sun heating treatment, a sudden temperature rises while a ferry came in to port at about 100 seconds and departure at about 500 seconds. The offset between both ROI temperatures indicated that SST differed for waterway and port area which could be in this case indicating transportation impact or different mixing of water masses. By this exemplary approach we revealed multiple patterns from sensor information, representing environmental and also transportation conditions.
As a consequence of changing environmental conditions like sun exposure, sea surface glint or thermal reflections (sky, clouds and also from harbor structures) the optical sensor

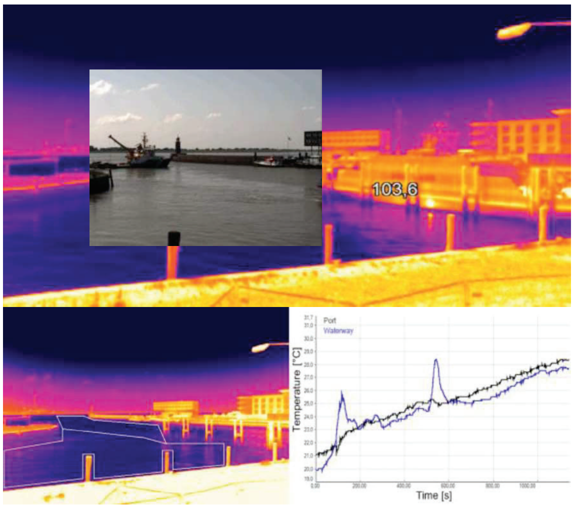

Fig. 7: Top: View from the base optical sensor system station (shown at top position in Fig.4), towards the port entry with ferry terminals (on the right), in visual and thermal infrared (pseudocolor) video image. Bottom: region of interests defined measuring fields for mean sea surface temperature determination in the Research Port area (left) and corresponding temperature time series profile.

information and covered scenes can become interfered. This has to be considered especially in mobile applications, where the covered scenes can change rapidly. In the case of interference, the video image information of sea surface conditions, like the presence of reflected sunlight, could even be useful for supplementary quality information and flagging criteria for above-water optical measurement systems [20, 21].
It should be noted that the measurements presented in this paper do not represent systematic measurements, but should be seen as use case demonstrations of the presented optical sensor systems. Because the amendment for absolute temperature regarding to air humidity and to sea surface infrared emissivity, which varies with viewing angle, salinity, and sea surface roughness [22, 23, 24].

(ii) Data collection for further analyses

Recording sensor data is handled similar as starting queries from the Admin Client Application interface. Input sources (live sensor data) could be separately addressed to a logging category, to set up file size (split up in chunks), recording interval or external triggers. Each server instance logs sensor data locally in raw format to enable replays of the recorded experiments reproducing the original scene (Fig. 2). Metadata like timestamps,

logging category or query orders can be saved in the original file or as separate metadata files, for example when using pre-existing video compression libraries which do not offer support for metadata. Thus far following sensor types and data formats are implemented in the server software:
LIDAR: Laser scanners, which scan distances in a plane around the sensor. The scan results are represented as a polar coordinate scan distance map.
Visual and infrared cameras: Cameras, which provide a stream of RGB or temperature images. A video bundle extends Odysseus to support video streaming and video writing functionality.
NMEA sensors: Sensors, which provide data in the NMEA format [14] over TCP/UDP or serial connections. This includes (differential) GPS sensors and wind speed sensors.
Text file sensors: By combining operators, sensor data continuously logged to text files can be readout. Timestamps can either be extracted from the log file, or can be extrapolated using information about the logging frequency.

(iii) Reuse of data

As initially mentioned, the experimental platforms are designed for system-engineering elaborations, e.g. testing new strategies, networking communication and information / data fusion for the generation of situational awareness in a Research Port, here provided by optical sensors. The experiment platform therefore also becomes important for data mining, ascertaining grounding experiment data and encouraged exchange for simulation tools. Recorded data should be used retrospectively to exploit further developments and process additional queries or test new applications without the need to re-run expensive real-world scenarios. The design of the system architecture facilitated therefore concurrently bilateral data interchange between real sensor nodes / simulated nodes and real word / simulated world, as shown in Fig. 1. Using this, complicated scenarios can be recorded once and then replayed several times. Additionally, replay sensor nodes can be used concurrently with simulations and real sensor nodes.

Conclusions and Outlook

We conceptualized and implemented an experimental maritime test bed for design and evaluation of sensor data fusion, communication technology and data stream analysis tools. The approach considered especially the application of distributed optical sensor technologies in maritime study areas, in here a port in Bremerhaven (Germany) as a reference Research Port field study area. The described setup offers a high flexibility for sensor interfaces, networking / communication connectivity, information processed query instances, as well as physical mobile properties of the sensor systems periphery. Therefore it can be applied in various research fields, from e-navigation over marine environment studies up to the generation of shared situational awareness.

Progressive engineering approaches were evaluated deriving requirements of the purposed framework assignment and conducted to the design of the system and the data stream architecture. We presented a general-purpose structure for processing interfaces by sensor systems, simulation modules, replay modules and also applications which could specify the needed data by an adaptive configuration component. The results of such modules can not only be sent directly to applications, but they are also integrated into the so-called world model which is key component for situational awareness.
Devolving the architecture concept into a data stream management system tool for sensor fusion processes and communication we were coping with additional requirements e.g. management of distributed sensors or provide tailored user interfaces.
Based on scenarios and use cases in the maritime study area we presented applications for situational awareness and facilitated a situational and marine environmental live picture. The developed optical sensor systems provide therefore a platform with flexible interfaces and sensor fusion technology to perform field studies within distributed areas for onshore and offshore applications. Thus our development embeds comprehensive aspects forward-looking for future indicatory multiplatform observations.

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