Maritime Applications of Augmented Reality – Experiences and Challenges

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Abstract. The paper summarizes experiences from applied research in visual computing for the maritime sector. It starts with initial remarks on Augmented Reality in general and the specific boundary conditions of the maritime industry. The focus is on a presentation of various concrete AR applications that have been implemented for use cases in maritime engineering, production, operation and retrofitting. The paper closes with remarks on future research in this area.

Keywords: Augmented Reality, Mixed Reality, Applied Research, Maritime Industry, Mobile Systems.

1 Introduction and Motivation

In this first section, we will give a short overview of Augmented Reality (AR) systems as well as the maritime sector that forms the application background of our applied research work.

1.1 AR Building Blocks

Augmented Reality can be understood as the confluence of computer graphics and computer vision. Azuma characterizes an AR system by the following three aspects [1]: AR (1) combines real and virtual objects in a real environment, (2) runs interactively and in real time, and finally (3) registers/aligns real and virtual objects with each other. If we translate this characterization from an end user's view to the view of the developer of an AR system, Azuma has identified three major building blocks [2] that are based upon a selection of basic technologies:

- Sensing/Tracking: Determine the position and orientation of the head or a mobile device and follow in real time. This is often done by fusion of various sensors such as cameras, gyroscopic and/or acceleration sensors.
- Registration: Derive real world coordinates as a prerequisite to mix real and virtual objects.
- Augmentation: blending real and virtual images and graphics. This compasses the display and/or visualization techniques.

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Due to the enormous boost in (mobile) graphics and the upcoming commercial availability of ergonomic AR devices such as the Google Glass, AR has gained outstanding attention – from the research community as well as from the general public.

1.2 Maritime Context

Implementing visual computing technology in the maritime domain differs in various ways from applications in sectors such as automotive, military, medical or cultural heritage. The last mentioned sectors offer the typical application field for prototyping of new interactive IT applications. The high R&D spending of medical, automotive and military companies on the one hand and sectorial funding schemes for cultural heritage especially by the European Commission and other public funding bodies can explain this situation.

Compared to those other sectors, the maritime forms a niche market which is typically characterized by relatively low R&D intensity, many small and medium-sized companies, and a conservative attitude [3]. However, the awareness of the maritime industry as an important economy is constantly rising. Individual sectors cover a broad range from cruise tourism over offshore oil and gas to fishery and seaborne transport. This can be underpinned by the following quote from the European Commission in their Blue Growth strategy [4]: "If we count all economic activities that depend on the sea, then the EU's blue economy represents 5.4 million jobs and a gross added value of just under €500 billion per year. In all, 75% of Europe's external trade and 37% of trade within the EU is seaborne."

Beside those economical differences, there are also various technical differences we have to cope with when implementing IT solutions for the maritime sector. Those bounding conditions are incompletely described as follows:

- We typically find harsh environments where mobile applications are faced with water and pressure (in underwater settings), dust and flying sparks (shipyards), splash water, extreme temperatures and heavy movements due to waves (aboard a ship).
- For underwater applications, we need to consider the specific physical effects such as refraction, deflection and attenuation that affect optical tracking as well as the registration process and visualization [5]. Color correction and distortion correction must be integrated into the AR solutions.
- Connectivity to networks such as a global navigation satellite system (e.g. GPS) or wireless data networks (3G) is sometimes limited or completely shielded on open sea and under water. Satcom networks are much more expensive and acoustic underwater communication is offering only a quite small bandwidth and high delay.
- A ship is not fixed but will roll, pitch and yaw. So – depending on the use case – we have to determine the movement of the ship relative to the earth and the movement of a person (or device) relative to the ship.
- The dockyard hall as well as the outer hull of a ship and even internal structures such as pipes and frames are quite uniform and offer quite few characteristic visual

features. When we just see a detail of the overall structure, it is often impossible to identify the correct position of the clipping.

- Ships can be quite big – not only in terms of physical dimension but also in terms of data volume. We can roughly estimate that a large ship has 10 times more parts than a plane and 100 times more parts than a car.
- Furthermore, there are some economical or organizational specialties to mention:

– Ships or offshore installations are not built in large volumes but as unique copies or a small series of two to five ships. The economy of scales is hard to reach here.
– The design systems used in the maritime industry are very production-focused. There are various CAD systems that are only used in the maritime industry, maybe in plant design, but nowhere else. The native APIs and data formats demand a very specific know-how when interfacing with this IT environment.

1.3 Related Work

Plenty of work has been done in various applications fields of AR (ref. Fig. 1). Most of the publications present research in medical training or assistance [6, 7, 8], the automotive sector [9], aerospace industry [9, 10]. Not as widespread but also visible in the research community is work in ambient assisted living [11], architecture and civil engineering [12]. A new trend is AR in production in the context of Industry 4.0 and Cyber Physical Systems [13, 14].

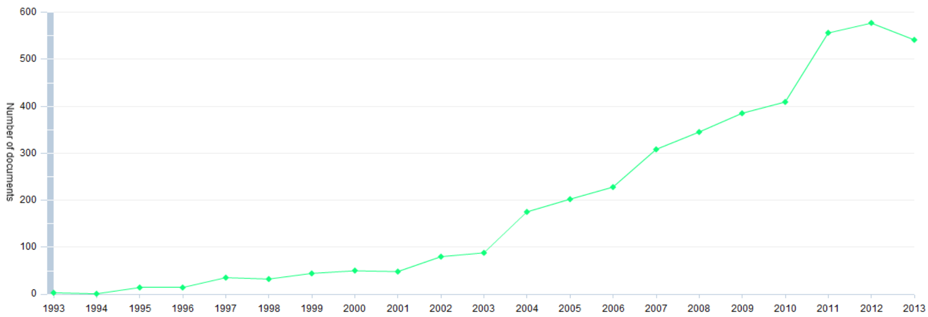

Fig. 1. Number of scientific publications with “Augmented Reality” or “Mixed Reality” in article title, abstract or keywords. (Source: Scopus; generated February 2014)

Those publications show that a large number of use cases has been addressed by (prototypic) AR systems. However, it is nearly impossible to easily transfer those systems to other sectors. All those solutions are designed to support a very limited task and do not offer the flexibility to adapt to similar settings. Most of the applications need a controlled environment in respect to lighting conditions or fast movements. And even their limited scope is the result of a time-consuming development process. So we can observe that there are just very few commercial applications of AR outside R&D.

From those findings we can argue that it is still necessary to concentrate on a particular domain to develop AR systems that fulfill the needs of a certain community with their bounding conditions.

There is a small number of publications that explicitly address maritime use cases of Augmented Reality. Among them we find navigation and watchkeeping and naval warfare [15-19], maintenance of ships [20], diver support [21], ship production [22], and two surveys [23,24].

2 Our Examples

The following Augmented Reality applications in different phases of the lifecycle have been developed by Fraunhofer IGD so far:

2.1 Sales and Marketing

Use Case. Especially in the maritime domain, AR still is an eye catcher at trade fairs or show rooms. Such an application neither has to be integrated into the existing IT environment nor does it has to support a complex process. For this reason, projects with sales and marketing often serve as a "door opener" to introduce Virtual or Augmented Reality in a company. In our project, a tablet PC is used to support the sales process for the retrofitting of ships. The tablet serves as a window to the "future" and shows the customer what his or her ship could look like with a new generation of rescue boats and davits. It is designed not for the real world, so we used large posters to visualize a cruise liner. The end user can choose between different augmentations: the new davit plus rescue boat in parking position, in swing-out position and with additional dimensions.

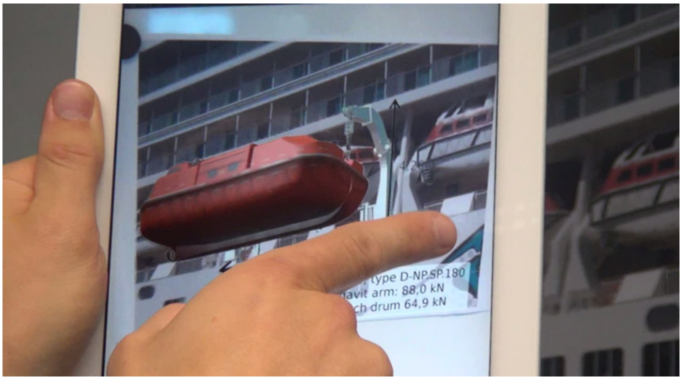

Fig. 2. AR application for the retrofitting of rescue boats and davits

Challenges. There have not been any specific challenges of the maritime sector due to the setting at a booth of a trade fair. The challenge here was to implement an application that is very robust, working with different lighting conditions and easy to use for the visitors without explanations.

Implementation Aspects. The application made use of Fraunhofer IGDs framework for mobile AR applications [25]. This speeds up the authoring phase and generates the content that will be read in by the player running on an iPhone or iPad and implementing markerless optical tracking – in our case with a poster tracker.

2.2 Product validation

Use Case. A kinematic simulation has been introduced in the design process to validate the model of a davit. To support confidence in the simulation, we implemented an AR application where the simulation was used as an overlay to real video of a physical acceptance trial. An animated wireframe model of the davit is rendered into the real video with the correct viewpoint [26].

Challenges. The challenging part of this project has been the poor video quality of the test trial and the fact that the small partnering company did not have much experience with 3D CAD, simulation and data exchange. These two challenges are not unique to the maritime sector but quite typical from our experience.

Implementation Aspects. We used a marker for a first pose estimation and then utilized the available CAD model for fine registration. The visualization was implemented with our VR/AR framework instantReality [27].

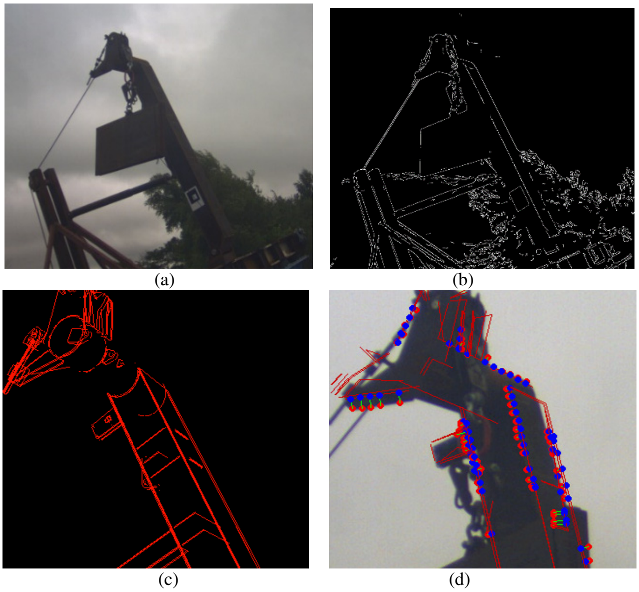

Fig. 3. The processing pipeline: (a) Original video frame; (b) extracted visible edges from the CAD model; (c) Extracted edges from the image; (d) Augmentation with control and corresponding hit points

2.3 Design and Production

Use Case. As already mentioned above, shipbuilding is characterized by a highly parallel process of design and production: Some parts of the ship are still in a very early design stage while other parts are already built. Similar requirements arise from late changes that can be demanded by the customer or stem from other disruptions in the process such as wrong dimension of delivered supply parts or significant deviations in production steps such as welding.

A specific use case is the design of pipes in the context of a bundle of existing pipes. Fitting pipes can be designed in physical context using an AR application where start and endpoint of the pipe can be selected [28].

Fig. 4. Mobile design application for pipe design in the physical context

Challenges. In this production-oriented use case, we have had to fulfill very high accuracy demands of the customer. The system is intended to send the design parameters of the pipes directly to the production department without additional post-processing.

Implementation Aspects. Without additional aids, we could not reach the necessary accuracy. A measurement tool with two illuminating points was used to align virtual straight pipe segments in such a way that they fit exactly through existing bolt holes.

2.4 Harbour Surveillance

Use Case. For harbor surveillance, the operator today typically has to switch between map view with radar and AIS information of ship tracks on the one hand and different video cameras on the other hand. Our objective with introducing AR in context of the Seatrax project is to bring both worlds together: For example the operator can look at the video system to instantly get all information about a vessel by touching on the ship, or she can start a radio call instantly.

This video mode offers the classical camera view – but augmented with annotation on every vessel with its name and optional meta data from the Vessel Tracking System (VTS). Using the *follow-me* function, the operator can stick the camera to a ship, and the camera automatically follows the ship. Also buoys, lights, navigation aids and sea marks are drawn as overlay into the video stream on the right position in the right scale and correct perspective.

Besides the AR mode, the system should offer a second mode to the operator: the virtual model mode. This mode presents a nautical map and/or a static 3D harbor model augmented with dynamic ship models as representation of vessels in the real world. Parametric VR ship models for different AIS ship types (e.g. fishing, towing, tug, pilot) will be adapted in length and breadth gained from the VTS. In this mode, the *bridge view* function allows to “jump” to any ship’s bridge. In this way, the operator has the same viewpoint as the captain and can check sight conditions. The other function in the virtual model mode is the *bird’s view* function to get an overview.

Fig. 5. Augmented harbor scene: (left) real video mode, (right) virtual model mode

Challenges. There have been three big challenges in the project: Firstly, the camera mechanic. For controlling the surveillance camera of Funkwerk, we used the MULTISEC protocol. Whereas the pan and tilt of the camera housing of Funkwerk is very precise (tenth degree), the built-in zoom mechanic is very slippery. The lens system has a hysteresis, so that the same input value leads to a different zoom factor depending on the zooming direction. This was solved by introducing discrete zoom steps.

Secondly, the correction of the lens distortion. The radial distortion of the lens is minimal. But the optical center (also known as principal point) is not in the center of the lens as assumed by most synthetic camera models. This is a big problem because we need to precisely synchronize the real camera with a virtual one. The camera model of the VRML standard does not regard this parameter. Our AR framework instant Reality [33] allows to set this parameter and provides an extended camera model on top of the VRML standard.

Thirdly, we had to cope with the delay given by the irregularity period of the AIS signals (10 sec. up to 10 min.). Ships’ AIS transmitters send AIS signals depending on different circumstances, e.g. their speed over ground, the current rate of turn, the availability of free time slots at the broadcast frequency. Assuming that a ship has a big inertia of mass, we implemented a simple linear interpolation. As an alternative position source, the system is able to connect with VTS to make use of the exact and frequently updated position derived from radar information.

Implementation Aspects. We developed a C# application connected with the AR framework instantReality via its' EAI (External Authoring Interface) and different connectors to the camera, to AIS and VTS as well as to an AIS simulation. The solution consequently uses a 3D world to correctly place and scale the sign posts with the ship name and additional information. The user can control the cameras via pan, tilt, zoom and focus, and the camera parameters of the augmentation will always mimic the current settings of the real camera. Pan, tilt, zoom and focus commands will be propagated to both the real camera and the virtual camera synchronously.

3 Discussion

Compared to AR applications in other areas, the maritime sector obviously raises some additional challenges. First of all, we have to find a solution for registration and tracking. The ship hull or the water shields GPS signals, so we have to rely on alternative technologies for an initial position. For practical reasons, optical tracking should not be based on markers but use implicit features. However, in many areas of the ship we find very similar objects such as long pipes or steel plates. So we need additional sensors and adequate sensor fusion to determine the user's pose. Outside the shipyard, we have a ship with a 6 DOF movement which makes the tracking problem even harder.

In sectors with mass products, we have high-quality 3D models from the design phase that are nearly 100% equivalent to the physical product. The digital 3D model of a ship from the engineering department will typically not cover all details or late changes due to complications in production or varying supplier parts. Furthermore, the virtual ship and the real ship will depart even more in operation with every part replaced during repair and overhaul. But without a correct 3D model, many AR applications are hard to implement in a robust way.

Mobile AR systems with integrated optical 3D reconstruction have the potential to replace the expensive process of laser scanning in some areas: e.g. they can be used to collect all the geometric information for detailed planning of a retrofit project for ballast water treatment.

Future AR applications also address underwater scenarios such as diver assistance for control and repair operations at the rudder or propeller. For those kinds of applications, we have to solve all the physical challenges of underwater settings such as optical refraction, challenging light situations and marine snow resulting in extreme noisy images.

4 Summary and Outlook

Augmented Reality is a promising approach to support users in many different situations. Specific AR applications for maritime use cases have to cope with a bunch of technical and economic challenges. Those challenges do not only affect the feasibility but also the business case for commercial usage. However, the increasing importance of the sea as the backbone of worldwide transport, the premier location for regenerative energy, a supplier of food for a growing world population, motivates (applied) research in this area.

In this article, we have presented several examples of AR applications that have been developed for end users in different sectors of the maritime industry. We have demonstrated that we can already find technical solutions for most of the difficult bounding conditions.

But there is still a long way to go: Additional research is necessary to prepare the ground for a further dispersion of AR in all sectors of maritime industry. The following topics are on our R&D roadmap:

Efficient authoring of AR content is a pre-condition for stakeholders in a market that is characterized by SME and the lack of economies of scale. Our tools that rely on available material such as manuals [25] or CAD data [29] are a first step in this direction.

Robust optical tracking – even under very poor conditions (e.g. underwater) – needs different steps of correcting the different physical effects such as color cast [30] or noise that would hinder a feature correspondence algorithm to work correctly.

Precise inship tracking is an important building block for nearly all AR use cases during operation of a ship. Here, we rely on fusion of various sensors with promising first results [31].

Cyber physical equivalence is our placeholder for a bundle of technologies that are needed within the context of Augmented Shipbuilding. It is about a continuous mutual alignment of the virtual world and the real world. A first small example of a 3D discrepancy check via AR in the outfitting phase was demonstrated successfully [32] but has to be extended to much larger volumes, must be seamlessly integrated into the environment and must be more flexible to be adaptive to similar scenarios.

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