Digital Assistance in the Maintenance of Offshore Wind Parks

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Abstract. Harsh environmental conditions, time pressure due to tightly calculated maintenance windows, complex technical systems and high quality standards determine the working environment for the maintenance and repair of offshore wind farms. Despite good qualifications and diverse training courses, maintenance technicians are reliant on information from manuals and checklists when performing their tasks and must document their work results in protocols. Both the supply of information and the data acquisition show a multitude of media disruptions. Hence, the processes on site and in the postprocessing are carried out slowly and uncertainly. The assistance system presented is intended to contribute to a consistently digital information flow and to support the technicians in a task-specific manner. Augmented Reality (AR) offers a way of presenting information and interacting with the assistance system during work execution. Using the example of the maintenance of crane systems used in a variety of ways in offshore wind farms, this article shows which potential can be tapped through digital assistance systems and AR applications.

1. Introduction
Trouble-free operation is crucial for the efficiency of offshore wind turbines. To ensure this, the operators need complex service and maintenance concepts, especially since the requirements for offshore maintenance are significantly higher than for onshore systems. The main reason for this is the limited accessibility of the systems in bad weather conditions and the associated dangerous execution of maintenance work on site [1-3]. Accessing the offshore systems is still necessary, since condition monitoring systems do not offer 100% monitoring of the systems, especially for the non-electronic or production-related areas of the systems. In Germany, the Federal Maritime and Hydrographic Agency (BSH) therefore expressly prescribes regular visual maintenance on site [4]. The diverse work required for this is planned in campaigns based on long-term weather forecasts and the personnel selected and trained accordingly. Nevertheless, on-site employees are dependent on documents such as manuals or checklists, which can be used to inspect and maintain the systems. The work carried out must be documented very carefully in some cases. However, the paper-based documents often lead to gaps in the information supply or incorrect or illegible test reports, which in the worst case can lead to the withdrawal of operating licenses for parts of the wind farms [5]. As part of the funded growth kernel "OWS M-V: Offshore Wind Solutions Mecklenburg-Western Pomerania" [6], a methodology designed
for the offshore area was developed for application-specific configuration of digital assistance systems to support maintenance technicians as a source of information and a documentation tool. The aim was to ensure consistent digitalization from campaign planning and maintenance to evaluation and accounting of the work. The assistance systems derived from this can empower employees through implemented AR representations and interactions to carry out their work, at the same time to provide themselves with information and to fulfill their documentation requirements. As part of this topic, the following key questions should be answered in this article:

1) How can maintenance workers in offshore wind farms be provided with digital information to carry out their work as required?
2) How can digital documentation of the work carried out be processed and meet the high quality and safety requirements in this area?
3) How must asynchronous digital information flows be designed to eliminate media disruptions and taking environmental conditions and actual work tasks into account?
4) How must a methodology for the configuration of digital assistance systems be set up with regard to both the software and hardware system design in order to meet the above requirements?

2. Theoretical foundations and state of the art
The operating phase of an offshore wind farm is the subject of a broad spectrum of decisions and thus opportunities to increase its efficiency even during operation. The optimization of operating and maintenance processes also includes developing solutions for problems that only arise in this phase of life and using them as lessons learned for the design of other parks [7]. This results in various strategies for the maintenance of the wind farms. Depending on the distance and the equipment installed, the maintenance technicians are then brought to the wind farms by ship or helicopter and remain at sea during the campaign or return to the nearest port every day [8]. The deployment of the service teams on site is therefore also dependent on the current weather conditions. Storms, high waves, bad weather and the distance to the coast require special procedures in terms of both logistics and the technologies and materials used [9]. Due to the harsh environmental conditions alone, maintenance campaigns are scheduled with great effort in the good weather phases of the year. The classic methods of production planning (program, process and resource planning, capacity leveling, process scheduling) are used in this context with adaptations to the planning of the campaign content [10]. With the determination of the campaign-specific work content, the documents for the execution of the upcoming work orders are then created. These usually include the technical documentation of the systems, maintenance manuals, checklists and test reports. Although the use of CMMS (Computerized Maintenance Management Systems) is already widespread, the documents for the offshore maintenance campaign are still taken paper-bound at sea and filled in manually. Back on shore, the documents are then processed in the service companies back office and made available to the wind farm operator as a test report. [5]

Many digital assistance systems already exist for the purpose of information assistance and documentation in the area of maintenance and repair [11, 12], some of which even offer information display through augmented reality [13]. These assistance systems, whether with or without augmented reality, serve the purpose of providing additional information as required and thereby performing difficult tasks more easily, more securely and with higher quality. Current research projects (StahlAssist, MARI, CyProAssist) are also approaching the problems in the topic of mechanical and production engineering and are addressing configurable systems or the connection to sensors as the basis for predictive maintenance strategies.

However, a holistic approach to the task-specific use of digital assistance systems under harsh environmental conditions has not yet been developed or is not available on the market. For this reason, this work is dedicated to this very topic. The results of this article should help to eliminate media disruptions in the information flows of maintenance processes through the consistent use of digital assistance systems for the provision of information and documentation in maintenance measures. For this purpose, a methodology is presented that should make it possible to design information flows as
required and to configure digital assistance systems in a task-specific manner, taking into account the expected environmental conditions and interaction possibilities.

3. Concept and implementation

The goal of enabling offshore maintenance processes digitally with mobile assistance systems required knowledge of the process and information requirements of the employees as well as the environmental conditions for the use of such systems. For this reason, the concept development and implementation were based on a detailed analysis of the current situation in maintenance campaigns of offshore wind farms and the derivation of a catalog of requirements with regard to the configuration of the system hardware, information flows and interaction options. For the further use of the analysis results, reference scenarios were created, by means of which the analysis results can be exemplarily presented in a wide variety. An example of this is the inspection and maintenance of maritime crane systems, as they occur in many places in offshore wind farms and are used for material transport.

The configuration of the information flows and the associated data exchange was designed according to the needs of the offshore environment. The possibility of online operation of the assistance system is not permanent in offshore wind farms. Rather, it had to be assumed that an Internet connection could only be established at a few specific times. This complicates the implementation of digital information flows in such a way that online data processing on the server side is rarely possible and therefore collected data and requested information flow asynchronously to the actual point in time when the maintenance work is carried out. However, it can be realistically assumed that an Internet connection can be established at least once a day during a maintenance campaign that is sufficiently enough for the synchronization of the data. By using a data exchange module, the use of the assistance system was designed and implemented in both online and offline mode. In offline mode, the online processing method is simply used on a local database server for the provision and processing of the data. The concept of demand-oriented information flow was developed on this basis (Figure 1). It defines an architecture of the information flow, which is composed of information requests, processing procedures, preparation processes and the information presentation. In addition to the process flows, the data and information processed in the respective process steps were also defined.

![Figure 1: Concept of a demand-oriented information flow in the assistance system](image)

The demand-oriented information supply is based on the specific requirements and environmental influences occurring during the maintenance measure. The configuration of the software and hardware information processing and provision is based on a morphological box (Figure 2). This methodology provides for a three-level process in which environmental influences and control options, as well as the various options for the design of user interfaces, are combined. This enables the assistance system to be
configured based on the actual user requirements given with the work tasks to fulfill (e.g. hands-free operability, use in confined spaces). This means that the assistance system, depending on the interaction options of the maintenance technicians, prepares information that is optimal for the application scenario.

In terms of hardware, there was a requirement that potential terminal devices simply had to be integrated into the diverse, multi-part equipment of the maintenance technicians. However, due to the sometimes very specific work requirements, there was no universal device type, so that a configuration method was developed to determine the optimal device for use, in which the respective results of the methods for demand-oriented information flows and the information processing taking place incorporated. The requirements for the presentation of information and interaction with the assistance system, as well as the specifics of the environmental influences specified by the scenario, are gradually transferred to a suitable hardware selection. As a result, based on the description of the application scenario and the requirements regarding a potential information supply, a recommendation regarding the use of a specific type of terminal device can be generated as the basis of the assistance system.

A modular system (Figure 3) is thus available, from which the properties of the assistance system can be put together as required, depending on the scenario-specific requirements. Functions for data exchange with the information platform, information processing, hardware selection and data processing for different user interfaces are combined in individual modules, which can be combined with one another as required. The assistance system is made up of four independent basic modules and supplemented with four individually usable but also combinable modules for user interfaces.

**Information processing:** This basic module contains functions for data storage and processing. At this point, the relevant data is stored and processing processes of the information flows are carried out. In terms of software architecture, this is the backend, which was designed based on SQL and .Net.

**Control:** This basic module is used for the central processing of user interactions. By connecting various UIs in the assistance system, the actions taking place there (gestures, voice inputs, pointer and key inputs) have to be centrally returned to standard requests, which can then be transferred to the backend. In terms of software architecture, this module can therefore be referred to as middleware.

**Webservice, synchronization:** As a communication center within the methodology for configuring application-specific assistance systems, this basic module is used for the data connection to parent systems, such as ERP, MES or CMMS. Its functions are designed for asynchronous information flows, so that this module enables both online and offline operation of the assistance system.
**Hardware selection:** The basic module for hardware selection is formally an independently executable program, which, however, as part of the entire methodology for configuring digital assistance systems, makes an important contribution to assessing the suitability of certain types of terminal devices for use in specific application scenarios. Based on the description of the work tasks, environmental conditions and possibilities for integration into the equipment of the workers, it provides suggestions for suitable types of devices on which the software-based assistance system can be used.

**List assistant:** The list wizard is the basic user interface for displaying and interacting with checklists and step-by-step instructions. Depending on the defined mode, information in maintenance procedures can be called up iteratively (checklists) or linearly (step-by-step instructions) using this UI.

**Display of drawings and pictures:** If drawings and illustrations are to be displayed in the assistance system, this UI module is used. It is designed to display 2D information that goes beyond simple texts and tables (e.g. searchable manuals or the display of images and drawings with zoom function).

**3D display of information:** With this user interface, 3D rendered information can be displayed, e.g. models originating from CAD systems or mixed reality content. These very computational and performance-intensive processes are implemented using the game engine Unity, which enables a live rendering of the information. The module is intended for the simple, intuitive presentation of very complex information, but can only be used on certain terminal devices.

**Audio/video input and output:** This UI module provides an option for audio-visual interaction with the assistance system. The voice control is provided by the system through the use of appropriate libraries (e.g. Microsoft Cortana) and combined with a corresponding audio output. Voice commands are reduced to a few terms for ease of use. In this way, workers can work completely hands-free and have no visual field restrictions. The photo and video documentation are also located in this module.

![Figure 3: Modules of the digital mobile assistance system](image)

In this way, the assistance system for information technology support in maintenance processes in offshore wind farms can be used in various configurations. This also includes the possibility of providing information in various levels of detail. This ranges from simple checklists to complex 3D models. Together with the appropriate hardware, information processing to accompany maintenance activities using augmented reality is also possible.

### 4. Use of augmented reality in the inspection of maritime crane systems

Using the example of the inspection of maritime crane systems, it could be shown that the assistance system enables maintenance technicians to carry out their work with methodically prepared presentation
of instructions and specific guidance. Since crane systems are installed in offshore wind farms in the railing area, hands-free operation of the assistance system is a prerequisite for their inspection, so that the maintenance technicians can secure or support the structure with one hand and use the other free hand to carry out inspection works. For this reason, there was a possible configuration of the assistance system with data glasses and the associated gesture control for interaction with crane maintenance. It therefore made sense to expand the assistance system with the option of processing and displaying the information using augmented reality, including the associated interaction options. In order to enable an immersive interaction with the assistance system and at the same time to comply with the demand-oriented approach to supplying information, a method was developed that, based on the user's point of view, can overlay reality with additional information. In the case of crane inspection, it was possible to identify individual systems on the crane using the user's viewing angle and to display the partial checklists necessary for this as AR holograms in the field of vision and in close proximity to the system selected in this way (Figure 4). This method is based on the previous scaling of a virtual 3D model and its overlay with the physical system. For this, a one-off target is required directly on the system, which can be used for scaling and overlaying. The already existing type plate of the crane can be used for this purpose, whereby the attachment and use of an additional target are not necessary. The maintenance technician then has the option of interacting with the displayed content via the gesture control and still using both hands for the actual inspection. He is guided through the inspection by means of color codes and pointed out gaps in the ongoing inspection process.

After the inspection’s completion, the data collected are processed in the assistance system and then forwarded to the connected information platform. The development and testing of the AR module of the assistance system was carried out on a model of a crane system that was specially produced by 3D printing and is used by the maintenance technicians on the offshore wind turbines to transport materials when transferring them into the platform or turbine.

5. Evaluation of the methodology for configuring digital assistance systems
The methodology for the demand-oriented configuration of digital assistance systems for the maintenance and inspection of technical equipment and other systems in offshore wind farms is evaluated in a multi-stage process. In the first stage, configurations on tablets and mixed-reality glasses were tested on the basis of reference scenarios from the areas of crane inspection, maintenance of escape
hatches and the inspection of the MGO system on the converter platform of the Arkona offshore wind farm, and the maintenance technicians’ experiences were recorded in a survey (Figure 5).

![Image](https://example.com/image1.png)

**Figure 5:** Evaluation of various configurations of the assistance system in the offshore wind farm

Due to the small sample size (n=4) in the first stage of the evaluation, no reliable statements can be made about the results of the test. However, trends can be described from which useful results could be derived for the further procedure of developing the methodology for the configuration of assistance systems. At this stage it could be demonstrated that the configuration method and the digital assistance system can be used for the work in the reference scenarios and support the information flows in the desired manner. The technicians were more convinced of the configuration of the assistance system on industry-standard tablet devices than a comparable range of functions on mixed reality glasses, which could be attributed to the unfamiliar handling of such devices and the lack of industrial applicability (since mixed reality glasses are currently not designed for industrial applications). The tests also showed some weaknesses in the scope of functions regarding the display and searchability of documents parallel to the environment of the assistance system. The configuration methodology was then supplemented by modules for displaying documents known to the technicians in their original formatting and enabling them to be searched. In a second evaluation stage, the methods are therefore tested again using further reference scenarios and the actual information flow performance of the assistance system compared to the conventional, paper-based method.

6. **Summary and outlook**

With the developed system there is a method by means of which information flows for the execution of the inspection and maintenance of offshore wind farms can be digitally designed without media disruption. The method was implemented as a function model of a configurable assistance system as an example for some maintenance scenarios, which is currently being subjected to further evaluations. These include tests both in laboratory operations and in actual offshore maintenance campaigns.

The functions and structure of the method for the application-specific configuration of assistance systems for mobile use in the maintenance of offshore structures make it possible to digitally accompany complex maintenance and inspection processes and thus create seamless, media disruption-free documentation. On-site maintenance technicians are provided with information optimally prepared for their needs and the environmental conditions and accompanied by digital instructions through the measure. The system acts as an assistant to the employee and supports the process with the required range of functions. The necessary information can be prepared in various levels of detail, as required, which ranges from the simple checklist to the graphically complex AR application.

The results of the methodology can also be transferred from the offshore wind sector to other industrial sectors, such as industrial plant construction or structural engineering. The methodology
provides the suitable basis for digitally mapping not only maintenance and repair work, but also processes in other life cycle phases, and to support employees in the execution of their work under industrial environmental conditions using mobile assistance systems and accelerate workflows. The data obtained through the collected feedback in the assistance system can also be evaluated and used for further measures (e.g. data input for Digital Twins). Used in the environments of one-off and small series production in mechanical and production engineering, such systems can form an essential basis for the development of knowledge databases and the planning and control of processes. For this reason, human-technology interaction and hardware suitability for industrial use must be promoted in further development steps.

References
[1] Svoboda P 2013 Betriebskosten als Werttreiber von Windenergieanlagen – aktueller Stand und Entwicklungen (Operating Costs as a Value Driver for Wind Turbines - Current Status and Developments) Energiewirtschaftliche Tagesfragen 63(5) 34-38
[2] Silva N and Estanqueiro A 2013 Impact of Weather Conditions on the Windows of Opportunity for Operation of Offshore Wind Farms in Portugal Wind Engineering 37(3) 257-268
[3] Thomsen K 2010 Visiting an offshore turbine, whatever the weather [Online]. Available: https://www.windpowermonthly.com/article/1044955/visiting-offshore-turbine-whatever-weather. [28.04.2020]
[4] German Federal Ministry for Economy and Energy 2019 Informationsportal Erneuerbare Energien – Wartung (Renewable Energy Information Portal - Maintenance) [Online]. Available: https://www.erneuerbare-energien.de/EE/Navigation/DE/Technologien/Windenergie-auf-Sek/Technik/Wartung/wartung.html. [28.08.2019]
[5] Wunderlich O, Petersohn A and Eggert M 2017 Durchgängige Digitalisierung von Betrieb und Wartung von Offshore-Windparks (Consistent Digitization of the Operation and Maintenance of Offshore Wind Farms), Presentation at Zukunftskonferenz Wind & Maritim 2017
[6] MCC Maritimes Consulting Center GmbH 2019 Offshore Wind Solutions Mecklenburg-Vorpommern [Online]. Available: http://www.ows-mv.de/. [28.08.2019]
[7] Sperstad I, McAuliffe F, Kolstad M a Sjømark S 2016 Investigating key decision problems to optimize the operation and maintenance strategy of offshore wind farms in 13th Deep Sea Offshore Wind R&D Conference, EERA DeepWind’2016
[8] Dewan A and Asgarpour M 2016 Reference O&M Concepts for Near and Far Offshore Wind Farms ECN
[9] Stiftung OFFSHORE-WINDENERGIE 2019 Offshore-Windenergie - Sauberer Strom vom Meer (Offshore Wind Energy - Clean Electricity From The Sea) [Online]. Available: https://www.offshore-stiftung.de/offshore-windenergie. [28.08.2019]
[10] Lasse M and Wunderlich O 2018 Vorausschauende Kampagnenplanung. Basis für eine effiziente Wartung von Offshore-Windparks (Predictive Campaign Planning. Basis for Efficient Maintenance of Offshore Wind Farms), Presentation at Zukunftskonferenz Wind & Maritim 2018
[11] instandhaltung.de 2017 Forschungsprojekt ADIMA - Intelligente Instandhaltung industrieller Maschinen (Research project ADIMA - Intelligent Maintenance of Industrial Machines) [Online]. Available: https://www.instandhaltung.de/news/intelligente-instandhaltung-industrieller-maschinen-290.html. [10.09.2019]
[12] Fraunhofer IFF and Fraunhofer IAO 2017 ArdiAS [Online]. Available: https://www.transwork.de/index.php/foerderschwerpunkt/schwerpunktgruppen/assistenzsysteme-und-kompetenzentwicklung/ardias/. [10.09.2019]
[13] Titov F, Friedewald A and Loeding H 2014 Augmented Reality zur kundenintegrierten Variantenplanung (Augmented Reality for Customer-Integrated Variant Planning) Industrie 297-316