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Automatic Content Creation System for Augmented Reality Maintenance Applications for Legacy Machines

Michael Weltin[a], Dominik Lucke[a,b]*, Johannes L. Jooste[c]

[a]Hochschule Reutlingen, ESB Business School, Alteburgstraße 150, 72762 Reutlingen, Germany
[b]Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Nobelstraße 12, 70569 Stuttgart, Germany
[c]Department of Industrial Engineering, Stellenbosch University, Joubert Street, Stellenbosch, 7600, South Africa

* Corresponding author. Tel.: +49 7121 271 5005; *E-mail address:* dominik.lucke@reutlingen-university.de

Abstract

Augmented reality (AR) applications have great potential to assist maintenance workers in their operations. However, creating AR solutions is time-consuming and laborious, which limits its widespread adoption in the industry. It therefore often happens that even with the latest generation machines, instead of an AR solution, the user only receives an electronic manual for the equipment operation and maintenance. This is commonplace with legacy machines. For this reason, solutions are required that simplify the creation of such AR solutions. This paper presents an approach using an electronic manual as a basis to create fast and cost-effective AR solutions for maintenance. As part of the approach, an application was developed to automatically identify and subdivide the chapters of electronic manuals via the bookmarks in the table of contents. The contents are then automatically uploaded to a central server and indexed with a suitable marker to make the data retrievable. The prepared content can then be accessed for creating context-related AR instructions via the marker. The application is characterized by the fact that no developers or experts are required to prepare the information. In addition to complying with common design criteria, the clear presentation of the contents and the intuitive use of the system offer added value for the performance of maintenance tasks. Together, these two elements form a novel way to retrofit legacy machines with AR maintenance instructions. The practical validation of the system took place in a factory environment. For this purpose, the content was created for a filter change on a CNC milling machine. The results show that inexperienced users can extract appropriate content with the software application. Furthermore, it is shown that maintenance workers, can access the content with an AR application developed for the Microsoft HoloLens 2 and complete simple tasks provided in the manufacturer's electronic manual.

Keywords: Augmented Reality; Context-awareness; Automatic content creation

1. Introduction

Augmented reality (AR) has great potential in industrial maintenance to support users during maintenance work. Nevertheless, development in this area has been slow or even stagnant in recent years. The reasons for this can be found in the complexity of content development. The majority of augmented content is still designed manually by developers [1]. Augmented reality applications are often designed for one purpose and can therefore only be used for a certain number of tasks [2]. Furthermore, budget limitations also pose a problem for companies [3]. The lack of budget can become problematic considering that AR is seen as a key technology in the industry and, together with context-specific adaptation, offers the possibility of competitive advantage [4]. However, modern approaches use object recognition and real-time data to create these applications automatically for different scenarios [5]. These modern approaches often do not consider that neither machines nor the environment are equipped with the necessary requirements for such AR solutions. The problem is that the

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prerequisites for implementing such solutions are unknown in existing machines. Therefore, the creation of such complex AR solutions, e.g. showing instructions directly with pointers on the real component, still cause a high development and implementation effort. Simple AR solutions required for a widespread application in industry that can be implemented rapidly do not exist so far. Automatically created content is almost impossible to implement on legacy machines. In particular, the lack of access or complete absence of data on existing machines means that animations for changing contexts can only be linked to existing components manually and with great effort. Here, the operator has usually only received instructions from the manufacturer on operating and maintaining the machine. To still benefit from AR's advantages, individual solutions for the individual machines are then created by the operator himself.

Since the cost of creating AR is usually high and the cost to the operators plays a significant role, this paper presents a low-threshold approach that can create AR content from existing information. This work, therefore, addresses the problem of what a cost-effective approach to creating augmented reality content looks like and what prerequisites must be fulfilled.

2. Related work

The potential of augmented reality is also evident in industrial maintenance. The use of this technology in maintenance management has been researched for more than 50 years. Significant progress has been made in the last two decades, which has accelerated the implementation in the industry. This opens new possibilities for the use and design of AR applications.

2.1. Authoring techniques

There are two ways to create AR: manually and automatically. This is also referred to as "authoring" in creating AR solutions. "Manual authoring" is when the content is made manually by developers or subject matter experts. This is not only the creation of, e.g. 3D models or other displayed content, but also the implementation thereof in the AR environment [1]. The manual creation techniques, in which at least one person still intervenes in the design of AR, are contrasted with automated authoring solutions. Here, the AR is created from existing data. This can be, for example, CAD models or text sections that are stored in a database and accessed by the creation software. An AR application is then automatically created from this existing information without the intervention of developers or experts [2].

2.2. Context-awareness

The efficiency of industrial maintenance work depends on the one hand, on the skills of the service technicians deployed and, on the other, on how they are supported in the maintenance tasks. This has also become clear to researchers in the field of AR in industrial maintenance. To increase the efficiency of the maintenance technicians, the right information at the right time is needed for the user [6]. When an AR dynamically adapts to the context and displays appropriate information for the user, it is called context-aware. According to the definition, a system is context-aware if it uses the context to offer relevant information and/or services to the user, whereby the relevance depends on the user's task [7].

2.3. Automatic and context-aware approaches

There are various approaches in the literature for the automatic creation of automatic and context-aware AR solutions. Regarding the provision of the content presented, the approaches require different prerequisites.

A look at the publications on content creation for automatically and contextually generated AR shows that the creation varies widely. For example, [8] designed a graphics-based model for contextual maintenance assistance with augmented reality and 3D visualization. The authors' solution consists of three layers: data sourcing, data handling, and maintenance assistant. The flow of user data, i.e., the data required to enable the technician on site to obtain the information needed, is conceptually strictly from the bottom up. The content creation happens in the data collection layer, which collects data from the product lifecycle management system and a computerized maintenance management system. Primarily, the CAD data of the models are needed to overlay the physical machine with 3D AR models [8]. However, content must not be created from an existing system. Content can also be created and adapted by subject matter experts so that this adapted content can then be used for the creation of AR [6]. Another possibility could be to link the technical information with the AR application. This approach presupposes that the information on the machines to be maintained is completely available to the user [9].

Another point of view is the creation of context-related AR from technical editing. A so-called technical editing system in which individual text modules are stored as information and can then be linked to the 3D model of the plant is required [10]. In these cases, the presented solution approaches are created for specific applications. Scaling to other applications would not only be possible with effort, as the prescribed requirements must be given. Particularly noteworthy are high-end approaches using a digital twin, a linked database, speech recognition, and translation software to create fully autonomous and context-aware three-dimensional AR applications. Here, research is still in its infancy, and this technology is not much more than a conceptual theory [11].

Looking at the publications on automatically and contextually aware generated AR, it becomes clear why there are few such solutions. The prerequisites for context-related creation for AR vary depending on the focus and solution path. However, it also becomes clear that none of the approaches examined offers a retrofittable solution for the operator side.

2.4. Available electronic manuals

Manufacturers of production equipment and other machinery provide technical documentation containing maintenance or servicing information. This ensures that product operators and service technicians are instructed

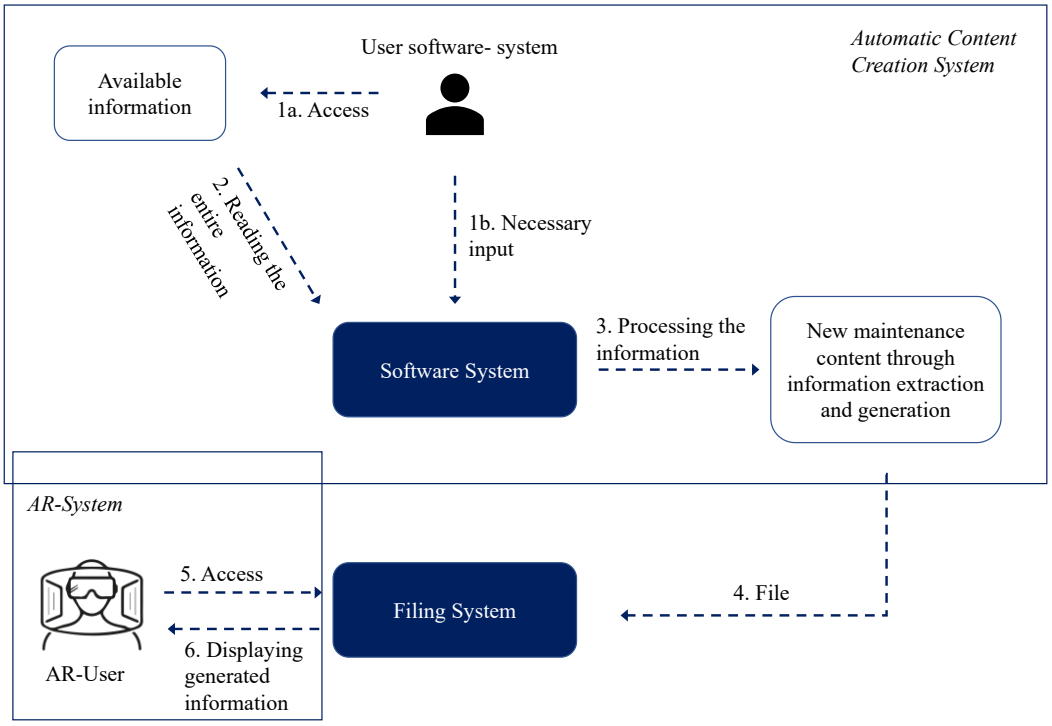

Fig. 1: Conceptual approach

adequately during maintenance and that the product is in working order and in perfect condition. However, manufacturers by no means do this only voluntarily. In many nations of the world, legislators oblige manufacturers to do this [12]. In the EU, these include European Community directives such as the Machinery Directive, the ATEX Directive, the Low Voltage Directive, the Pressure Equipment Directive and the Product Safety Directive, which have been transposed into national law by the member states (e.g. German Product Safety Act) [13]. For the design of technical information products, many technical editors are guided by the applicable standards. This information product must always be available on paper for legal reasons to protect the manufacturer. This is because it cannot be assumed that users can access a device that can display digital content [14]. Experts in the field of technical writing agree that manufacturers should also provide customers with a digital version of these instructions to avoid the cumbersome handling of paper-based documents [15]. Another advantage of a supplied digital manual is that the customer can reprint the manual or parts of it themselves, if necessary. These digital instructions can be in MS Word, PDF, or HTML. In this case, manufacturers mostly rely on digital manuals in PDF format [13]. This is primarily because any manual that can be printed can be converted into a PDF without additional effort. PDFs can be processed as a format by all standard devices. Furthermore, a common form of a digital information product offers the advantage that it guarantees certain data security over the years.

The design of such electronic instructions is governed by the IEC/IEEE 82079-1 standard. IEC/IEEE 82079-1 is a standard published by the International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE) to produce useful information. This is first and foremost a standard, which covers the principles and general requirements. It is a so-called cross-sectional standard. It can be applied comprehensively to various products, including industrial equipment [16].

3. Approach

The requirements for this approach are instructions provided by the manufacturer. The idea is to use a software tool, that extracts maintenance-relevant sections automatically from the instructions provided. Furthermore, these sections are linked with a unique marker which automatically generated. By attaching this marker to the appropriate component on a machine serves as a context-aware connection between the component and the augmented content. If the AR system detects the marker, the content is automatically displayed.

The general principle of operation and the requirements for the automatic content creation system are described in the following. These consist of the extraction of the content on the one hand and its provision on the other. A schematic overview is given in Fig. 1. The general prerequisite for the system is an existing user accessible electronic information product that complies with the standards according to IEC/IEEE 82079-1.

3.1. Content extraction

Fig. 1 shows the schematic structure of the approach. The system consists of a software component for automatic information extraction and processing and the AR system. If the user has access to the electronic manual (1a.), they can transfer the necessary information to the content creation system (1b.). An interface is required for this. Information can be accessed via the table of contents to meet these requirements. However, it is not the text of the table of contents that is read but the bookmarks and links behind the respective

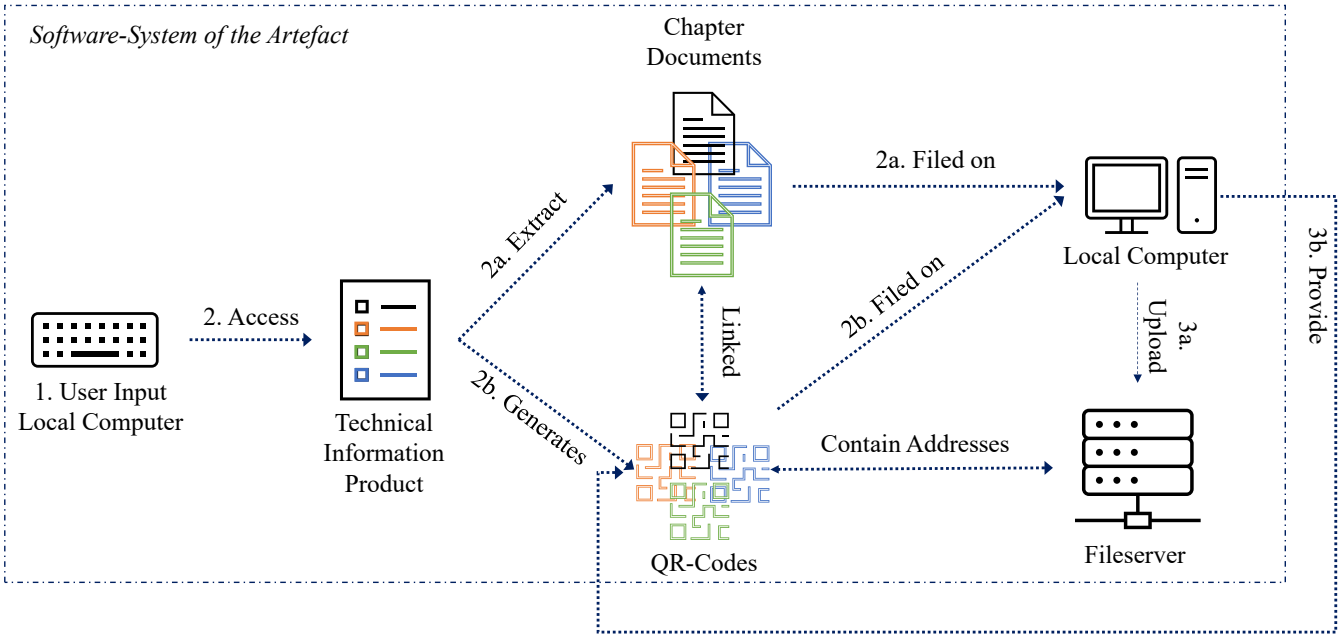

Fig. 2: Content creation system

chapter headings. This has the advantage that the bookmarks are recognized independently of the language, and the prototype is thus designed to be language independent. To do this, the software program opens the documentation in the background and searches for the bookmarks mentioned in the table of contents. Using these bookmarks, the software can determine the page on which the chapter begins (2.). To ensure that no information is lost, the bookmark of the next chapter heading is also determined automatically. In this way, the next chapter's page number can also be determined (3.). This ensures that all chapter contents are displayed. An AI-based approach was also considered for information extraction. However, it turns out that the AI is not capable of outputting connected image-text references with a comparable effort to the current approach.

3.2. Content provision

For the information not only to be extracted but also to be retrievable, the documents must be made available. The documents are located on the local computer of the executing user after being subdivided into individual chapters (Fig. 1). The problem is that an external user cannot access these documents. To display the correct information to the service technician on an AR device, they must have access rights to the documents. In addition, these documents must be available around the clock, as many manufacturing companies operate in shifts and produce 24 hours a day. To make this possible, the split content is stored directly from the local computer to a central location (4.).

4. Implementation

The electronic instructions are used as PDFs to implement the automatic content creation tool. Various challenges are associated with the analysis of extracting data via the bookmarks in the table of contents from digital information products. The difficulty is to find a common basis for different information products so that information can be extracted automatically from as many instructions as possible while guaranteeing operability. In the search for a uniform regulation for the design of information products, reference is made in the literature to the IEC/IEEE 82079-1 standard for the creation of instruction manuals [17]. In this context, this standard also covers the requirement that the advantages of digital navigation in the form of bookmarks are to be used in the table of contents.

The Python programming language was used to implement the final approach (Fig. 2). The tool tkinker is used for the input mask. The user can access existing information products via the input mask and provide the software with all the necessary information required for content creation and provision (1. in Fig. 2). The input mask generated contains the information required by the software for content creation and provision:

- Location of the original file
- Desired location of the extracted chapters and associated markers
- Address of the file server
- Login name of the user
- Password of the user
- Storage path on the file server

A file server is used to make the information available. A file server is a central server in a network like those found in many companies. The server offers users a central storage location for files. A server administrator controls access rights to these files. If the file server is connected to the internet and set up accordingly, access is possible via the local network and remotely. In this way, users can also access the stored files while on the move or store files on the file server [18]. To enable users from outside to access the content, the chapters are directly marked with an individual marker. This marker later enables the service technician to access the provided content via the AR application. The Python library paramiko was used

for the automated upload (3a.). In addition, various libraries were used for the content extraction (2a.). PDFMiner is used to read out the bookmarks of the table of contents. PyPDF2, on the other hand, is used to split the PDF documentation and thus generate a separate document for each chapter (Fig. 2). The documents are also saved as PDFs. Comparing the advantages and disadvantages of conventional AR markers with QR code markers, it becomes apparent that QR codes are the better solution for the artefact. This is partly because the choice of a file server as the central storage location has already been determined. Thus, the QR codes can provide access via a URL and download and display the documents. QR codes can store the URL of a document on the file server, and the end device can thus directly access the appropriate document by capturing the information on the code. The Python tool qrcode can quickly create unique QR codes for each file path (2b.). This means that a suitable code is generated for each chapter, which contains the URL to the storage location on the file server. These are then stored on the software user's local computer so the user can print the codes directly (3b.).

5. Validation

The practical validation of the system took place in a research factory environment. For this purpose, the content was created for a filter change on a CNC milling machine. An EMCO Concept Mill 260 was selected to validate the system's function. The model is a modular CNC milling machine. The manufacturer provides its customers with the original operating instructions for the machine in paper format and electronically as a PDF. A local computer and a file server are used for practical implementation. In this case a Raspberry Pi 3 is used as file server to provide the content. This serves as a file server on which the generated content is stored. Furthermore, a Microsoft HoloLens 2, on which a suitable AR solution is installed, is used to display the content to the user.

For the validation, the first step was to store the electronic information product provided by the manufacturer in a directory on the user's local computer. The information product is the original information product in electronic form. The language of the output used is German. Then the path of this directory is inserted into the software solution. The path where the extracted documents and the QR codes are to be stored is also entered into the software. In the next step, the IP address of the Raspberry Pi is output and inserted into the developed software solution by the user. This is needed because Raspberry Pi represents the local file server. In this case, the local computer and the file server are in the same network, but this is not necessarily due to the data transfer via Secure Shell (SSH). In addition, a directory is created on the Raspberry Pi where the extracted information will later be stored, and the path of this directory is entered as the storage path in the developed software solution. After the program is started, it takes about 30 seconds to extract the information from this manual. Two different maintenance cases have been implemented on the machine. One is the chapter "Visual inspection of all tubes/pipes", and the other is "Filter replacement". For the visual inspection, the appropriate QR code is placed above the viewing window of the machine. This contains the document's address stored on the Raspberry Pi (Fig. 3). The QR code, linked to the maintenance instruction "Filter exchange", is attached to the back of the machine, next to the pneumatics.

For the user to access the created content AR glasses are required. A Microsoft HoloLens 2 was used for this. An AR application developed for this application was installed on it. This gives the user feedback when scanning the attached QR codes. The user is shown a square field that overlays the QR code. In this field, the user is then shown the URL to the stored file on the file server (Fig. 3).

Fig. 3: Visual feedback

When the user has scanned the code, the respective content is opened in the browser of the glasses (see Fig. 4). In addition, content in the browser can be placed by the user anywhere in the room. This allows the content to be positioned as the work task requires and as is comfortable for the user.

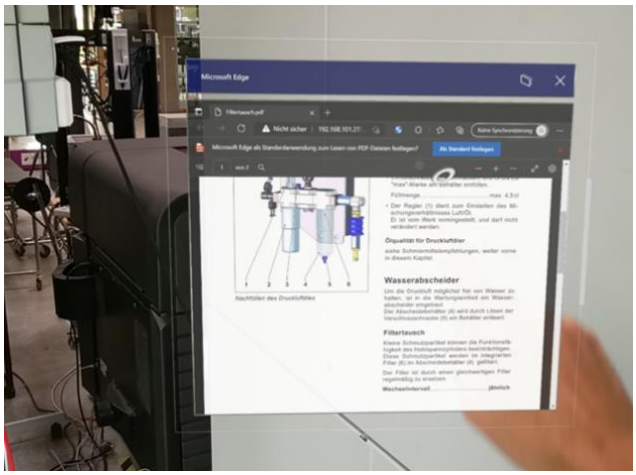

Fig. 4: Displayed content

6. Conclusions and future recommendations

The implementation and validation of the AR content creation system in an industrial environment has proved its application in a real-world scenario. Both the extraction of the information with the developed software and the upload to a file server were successfully achieved without problems with the devices used. The validation showed that users can provide all relevant information to the system via the input mask

provided and that the content is generated without any further effort. The printed QR codes accessed and displayed the appropriate information when the user has targeted them with the AR application on the HoloLens 2. The users were able to get the correct and expected visual feedback. In addition, the application also works when the QR codes are stuck upside down. Here, the visual feedback is twisted, but the generated contents are displayed correctly in the browser.

There is potential for improvement in a hardware solution that can recognize smaller QR codes and equip the QR codes with information that is recognizable to the user without glasses. A letter or symbol could be embedded, which on the one hand, would be helpful for the application and, on the other hand, would signal the respective voice output. Several subchapters are sometimes shown on one page which could confuse the user. Nevertheless, the implementation of the approach can be assessed as predominantly positive. The goal of offering a cost-effective alternative for automatic and context-related AR applications was achieved in this case. The augmented content faded at the right places without the user's intervention. This low-effort solution can be a sensible solution for individual work steps.

Concerning the system, further recommendations can be made. On the one hand, using PDF information products is a limitation. In future, functions could be integrated here that, on the one hand, also include PDF information products that do not comply with the standard. On the other hand, it should also be possible to have different formats in the future. One factor not yet considered in the work is the legal use of the content. Especially from the operator's point of view, it should be clarified in advance to what extent the tool can be used with the original instructions of the manufacturer. Agreements or licensing are conceivable here. The use of QR codes is a simple and practical solution. But here, too, a possibility should be developed to design them so that the entry via a QR code leads to a higher level so that a code does not have to be attached for each chapter. The approach outlined is intended to be a basis for further cost-effective ones. This work can also be built upon. An extension of the work is also conceivable, in which the QR code also serves as a marker for automatically generated images, animations or other assistance for the user. In the long term, in addition to the proposals mentioned above, consideration should also be given to integrating AI into the solution. This would make it possible to also consider unstructured documents in the solution with the approach shown. Furthermore, a combination of the existing approach in combination with artificial intelligence could deliver a significant increase in the precision of the displayed content.

References

[1] Palmarini R, Erkoyuncu JA, Roy R, Torabmostaedi H. A systematic review of augmented reality applications in maintenance. Robotics and Computer-Integrated Manufacturing; 2018;49:215–35.

[2] del Amo IF, Erkoyuncu JA, Roy R, Palmarini R, Onoufriou D. A systematic review of Augmented Reality content-related techniques for knowledge transfer in maintenance applications. Computers in Industry; 2018;103.

[3] Hülsebömer S, Teichmann M, Rosza A. Studie Virtual Reality / Augmented Reality 2019; 2019.

[4] Bischoff J, Taphorn C, Wolter D, Braun N, Fellbaum M, Goloverov A, Ludwig S, Hegmanns T, Prasse C, Henke M, Hampel M ten, Döbbeler F, Fuss E, Kirsch C, Mättig B, Braun S, Guth M, Kaspers M, Scheffler D. Erschließen der Potenziale der Anwendung von Industrie 4.0 im Mittelstand. Studie im Auftrag des Bundesminesteriums für Wirtschaft und Energie; 2015.

[5] Akbarinasaji S, Homayounvala E. A novel context-aware augmented reality framework for maintenance systems. AIS; 2017;9(3):315–27.

[6] Erkoyuncu JA, del Amo IF, Dalle Mura M, Roy R, Dini G. Improving efficiency of industrial maintenance with context aware adaptive authoring in augmented reality. CIRP Annals; 2017;66(1):465–8.

[7] Abowd GD, Dey AK, Brown PJ, Davies N, Smith M, Steggles P. Towards a Better Understanding of Context and Context-Awareness: Springer, Berlin, Heidelberg; 1999. p. 304–316.

[8] Abramovici M, Wolf M, Neges M. Graph-Based Model for Context-Aware Maintenance Assistance with Augmented Reality and 3D Visualization. Advances in Through-life Engineering Services: Springer, Cham; 2017. p. 367–386.

[9] Gattullo M, Dalena V, Evangelista A, Uva AE, Fiorentino M, Boccaccio A, Ruta M, Gabbard JL. A Context-Aware Technical Information Manager for Presentation in Augmented Reality. IEEE Conference on Virtual Reality and 3D User Interfaces (VR); 2019. p. 939–940.

[10] Gattullo M, Evangelista A, Manghisi VM, Uva AE, Fiorentino M, Boccaccio A, Ruta M, Gabbard JL. Towards Next Generation Technical Documentation in Augmented Reality Using a Context-Aware Information Manager. Applied Sciences; 2020;10(3):780.

[11] Lossie K, Leo Nuy, Jonas Rachner, Robert H. Schmitt. Adaptive und kontextspezifische technische Handlungsanweisungen. Zeitschrift für wirtschaftlichen Fabrikbetrieb; 2020(12):934–7.

[12] Juhl D. Technische Dokumentation: Praktische Anleitungen und Beispiele. Berlin: Springer; 2005.

[13] Kothes L. Grundlagen der Technischen Dokumentation: Anleitungen verständlich und normgerecht erstellen: Springer; 2011.

[14] Oehmig P. Wie Sie eine benutzergerechte Technische Dokumentation (ein Informationsprodukt) planen, konzipieren und gestalten. Düsseldorf: Euroforum Verlag; 2011.

[15] Meluzov N, Friedewald A, Elzalabany A, Lödding H. Aufwandsarme Erstellung von Augmented-Reality-Anleitungen für die maritime Instandhaltung. In: Freiherr von Lukas U, Bauer K, Dolereit T, Flach G, editors. Mit 3D Richtung Maritim 4.0: Fraunhofer Verlag; 2019. p. 31–44.

[16] IEC/IEEE; 2019. IEC/IEEE 82079-1: ation of information for use (instructions for use) of products - Part 1: Principles and general requirements;01.110(82079-1): Beuth Verlag. Berlin.

[17] Schlagowski H. Technische Dokumentation im Maschinen- und Anlagenbau: Anforderungen. 2nd ed. Berlin, Wien, Zürich: Beuth; 2015.

[18] Matthews J, Herne J, Deshane T, Jablonski P, Cherian L, McCabe M. Data protection and rapid recovery from attack with a virtual private file server and virtual machine appliances. Proceedings of the IASTED International Conference on Communication, Network and Information Security (CNIS 2005); 2005. p. 170–181.