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A Framework to Establish an Assistance System by Using Reality Technology in Maintenance

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Abstract

Maintenance is an increasingly complex and knowledge-intensive field. In order to address these challenges, assistance systems based on augmented, mixed, or virtual reality can be applied. Therefore, the objective of this paper is to present a framework that can be used to identify, select, and implement an assistance system based on reality technology in the maintenance environment. The development of the framework is based on a systematic literature review and subject matter expert interviews. The framework provides the best technological and economic solution in several steps. The validation of the framework is carried out through a case study.

Keywords: smart maintenance; reality technology; augmented reality; mixed reality; virtual reality; assistance system

1. Introduction

Digitalization leads to increasingly complex and knowledge-intensive maintenance. The areas of knowledge management and skills development play a key role [1]. Technical support through assistance systems (AS) based on reality technology (RT) have the potential to address these challenges [2]. These digital ASs enhance the cognitive performance of maintenance personnel by making information accessible to everyone at any time and in any place [3]. The information, data and knowledge can be individually adapted to the situation and abilities of the respective user. Thus, maintenance personnel is able to handle the immense amount of data by receiving the relevant information and making the right decision based thereon [4,5].

Although the benefits are known, the industrial usage of ASs based on RT in maintenance is not prevalent. The reason is that companies are not able to determine which type of ASs – visual ASs, auditive ASs or tactile ASs – and which kind of RT – augmented reality (AR), mixed reality (MR) or virtual reality (VR) – is suitable for which maintenance activity. In addition, obstacles in implementation arise, such as lack of internet connection in the production environment or lack of acceptance by employees and managers. Furthermore, the cost-benefit ratio is considered insufficient [2,3]. Therefore, companies need to able to evaluate the technical and economic aspects for the application of ASs based on RT in maintenance.

1.1. Purpose of this paper

This paper presents a framework that assists companies with the identification, selection and implementation of ASs based on RT in maintenance. The proposed framework is referred to as *decision support framework for reality technologies in maintenance* (**DSF-RTM**). The DSF-RTM is application-oriented as well as practical and intended for use in industrial maintenance. In addition, the DSF-RTM is not delimited to a specific industry or company size and is thus generic. The user

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of the DSF-RTM is not required to be an expert in the field of ASs based on RT.

1.2. Research approach

The research approach to establish the DSF-RTM includes three phases:

1. A systematic literature review and semi-structured interviews with subject matter experts in maintenance on application characteristics and implementation requirements of ASs based on RT in maintenance.
2. The development of the application-oriented and generic DSF-RTM that does not require its user to be an expert in the field of RT.
3. The validation through a case study using the DSF-RTM to investigate an RT-based solution for the maintenance of a milling machine in a learning factory.

2. Systematic literature review

To gather information about the application characteristics and implementation requirements, a systematic literature review on ASs based on RT in maintenance is conducted. Since RT presents the umbrella term and to obtain specific information, the systemic literature review is carried out for ASs based on AR, MR and VR in maintenance.

Regarding the application characteristics, the environment and the nature of the maintenance application are decisive for the selection of an AS based on RT. The aspect of the environment includes, for example, the existing noise or light conditions. The aspect of the nature of the application involves, for example, whether and what type of transport is required for ASs based on RT [6,7].

Furthermore, ASs based on AR are utilised on the one hand in the execution of maintenance. Regarding the advantages and disadvantages in contrast to traditional methods such as paper-based instructions, the results are diverse. The mentioned advantages are reduced time and error rates as well as improved user experience. However, in some of the literature, no improvements in time and error rates are recorded [8,9]. On the other hand, ASs based on AR are employed for training in maintenance. The advantages compared to traditional training methods include the possibility that novices can carry out maintenance tasks on site and thus, only a minimum of knowledge is required. In addition, ASs based on AR enable a simplified representation of training material, thus increasing the efficiency of training [10,11].

ASs based on MR are applied for training but primarily to carry out maintenance. The assessment compared with traditional training methods indicated that costs and error rates are reduced, flexibility is increased and usage is simplified but performance is not significantly improved [12]. Furthermore, the evaluation compared with traditional methods in the line of execution resulted primarily in benefits: reduced time and costs as well as improved accuracy, efficiency, and performance. In particular, the possibility of presenting complex information in a simple and efficient user interface is emphasised. A single drawback is mentioned that the processing power of the output devices is insufficient [13,14].

ASs based on VR are employed in the line of execution but primarily for training in maintenance. For the execution of maintenance tasks with VR compared with traditional methods, it is determined that costs and time are reduced but that technical challenges can arise due to ASs based on VR [15,16]. For the application of ASs based on VR for training, the advantages compared to traditional training methods are diverse. Some authors reported a reduction in time and an improvement in performance is reported while others reported the opposite. Other benefits include increased efficiency, flexibility, and safety as well as the possibility to train several people at the same time. Further disadvantages are not identified [17,18].

Regarding the implementation requirements, factors concerning employees, costs, technology are identified as essential for the implementation of ASs based on RT in maintenance. In terms of employees, the important aspects are that the employees accept and are able to use the new technology [8,12]. Moreover, a company is required to have sufficient financial resources to invest in an ASs based on RT [9,14]. Furthermore, three different aspects are relevant in terms of technology. First, the technologies and machines employed in the intended maintenance environment are required to have a certain level of maturity for the successful use of ASs based on RT. Second, a certain degree of digitalisation is essential for the digital ASs. Third, the data used for ASs based on RT must be appropriately protected [7,16].

3. Semi-structured interviews

Since insufficient information is available in the literature on the topic of ASs based on RT in general and in the field of maintenance in particular, semi-structured interviews were carried out. Furthermore, the aim is to develop an application oriented as well as practical framework and therefore, gathering empirical data from the industry is beneficial.

The semi-structured interviews were conducted with nine participants who are engineers, directors, or consultants of maintenance management in the following sectors: consulting; healthcare; the petrochemical industry, the liquid beverage industry, and the electricity industry with a focus on traditional and renewable energy sources. In addition, the experts are from South Africa as well as the United Kingdom and represent national as well as international companies.

Regarding the application characteristics, the type of RT is selected based on the nature of the application. AR and MR are preferred for the execution of maintenance tasks, while VR is favoured for maintenance training or planning tasks. The selection of an output device depends on the nature of the application.

Regarding the implementation requirements, the results of interviews show that seven requirements play a role for the implementation of ASs based on RT in maintenance: skills of employees, financial resources, acceptance of RT by employees, maturity of technologies and machines, degree of digitalization, data security as well as safety. In terms of financial resources, the conclusion is drawn that in addition to the costs, the benefits of using ASs based on RT in maintenance have to be considered. Thus, the costs have to be weighed up against the benefits to make a profound decision on whether the investment in ASs based on RT is profitable. Furthermore, the individual circumstances of the maintenance application or the company in general determine which requirements are more important than others. Thus, a generally valid sequence for the relevance of the implementation requirements for maintenance applications cannot be derived.

4. Decision support framework for reality technologies in maintenance

This section presents the application-oriented and generic DSF-RTM. The aim of the DSF-RTM is to assist companies with the identification, selection and implementation of ASs based on RT in maintenance. Based on the data gathered in the systematic literature review and the semi-structured interviews, the layout requirements (LR) and content requirements (CR) shown in Table 1 are defined for the DSF-RTM.

Table 1. Overview of requirements for DSF-RTM

Requirement		Description
Layout	LR1	User-friendly handling
	LR2	No previous knowledge about RT required
Content	CR1	Consideration of hardware and software
	CR2	Consideration of implementation requirements
	CR3	Feasibility Study
	CR4	Guideline for implementation

Against the background of the requirements, the design shown in Fig. 1 is derived for the DSF-RTM.

The proposed framework is structured into four steps:
1. Context analysis
2. Implementation requirements analysis
3. Cost-benefit analysis
4. Implementation guideline

In the first step, the context analysis, the optimal AS based on RT and its costs for the intended maintenance application of the user are identified. The second step of the DSF-RTM includes the analysis of the implementation requirements as well as the adjustment and costs necessary to achieve these. The third step of the DSF-RTM consists of comparing the costs and benefits resulting from the application of the AS based on RT in maintenance. In the case that the costs outweigh the benefits, a decision has to made whether to investigate an alternative solution or to exit the framework. In the case that an alternative solution is to be investigated, the next decision is to determine whether the cost for the hardware and software, the implementation or the maintenance are to be adjusted. In the case that the benefits outweigh the costs, an implementation guideline is provided as the final step of the DSF-RTM. In the next sections, the four steps and the respective methods utilised for the DSF-RTM are discussed in more detail.

4.1. Context analysis

The objective of the context analysis is the identification of the optimal AS based on RT for the user's intended

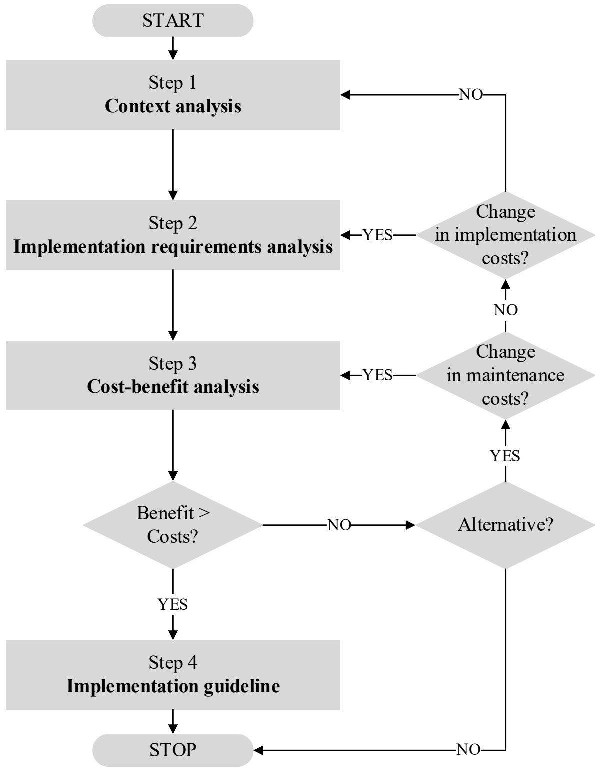

Fig. 1. Flow chart of the DSF-RTM

maintenance application with the respective costs. Since of the main hardware components – output device, input device and tracking device – and the main software component – development platform – of ASs based on RT, the output device is the decisive element, the context analysis starts with the identification of this hardware component.

The optimal output device is on the one hand identified based on the application environment. Depending on whether the environment is bright, noisy or both, a visual, auditive or tactile output device is recommended. On the other hand, the identification of the optimal output device is conducted based on the nature of the application. Depending on whether superimposed virtual content (AR), interaction with virtual content (MR) or only the virtual world (VR) is required, a recommendation for the type of RT is given. The identification of the remaining hardware and software components is based on their combability with the identified output device.

Subsequently, the hardware and software costs are assessed. Since several cost assessments are performed within the DSF-RTM, to ensure their comparability, the cost metric and respective rating shown in Table 2 are defined as a standard for the DSF-RTM. The definition of the ranges is based on the analysis of the identified costs throughout the framework for the lowest and highest costs as well as in which range the most costs are identified.

Table 2. Cost metric applied throughout the DSF-RTM

Range of costs	Cost metric	Rating
X > 5.000€	High	5
1.000€ < X <= 5.000€	Medium	3
X <= 1.000€	Low	1
X = 0	None	0

The currently available hardware and software components of ASs based on RT are assessed based on the cost metric.

Finally, the total hardware and software costs are calculated. For the hardware, the ratings for the output device, input device and tracking device are summed, which is shown in equation 1. In the case that multiple devices are determined for input or tracking, these ratings are added. The following abbreviations are applied for the clear presentation of the equation: rating (R), hardware costs (HC), output device (OD), input device (ID) and tracking device (TD).

$$R_{HC} = R_{OD} + R_{ID} + R_{TD} \quad (1)$$

Table 3 shows the cost metric utilised to classify the hardware costs as low, medium, or high costs and indicates the respective rating.

Table 3. Cost metric and rating of hardware costs

Range of rating	Cost metric	Rating
X > 18	High	5
8 < X <= 18	Medium	3
X <= 8	Low	1
X = 0	None	0

For the software costs, the rating identified for the development platform is to be considered since the costs for the development platform are the only cost factor for the software.

4.2. Implementation requirements analysis

The objective of the second step is to identify the adaptations to fulfil the implementation requirements for the AS based on RT into the maintenance environment and the respective costs. The seven implementation requirements derived from the systematic literature review and evaluated for relevance in the interviews are used as a basis. The reason why financial resources are defined as a requirement is that the implementation of AS based on RT is only feasible if the investment is economically profitable. Since a cost-benefit analysis is applied in the third step, the requirement for financial resources is not taken into account in this step.

First, the implementation requirements are weighted. Since no generally valid sequence for the relevance of the requirements could be derived from the interviews and to enable the evaluation based on individual circumstances, the implementation of a pairwise comparison is proposed. Thus, the relevance of the order of the individual requirements is determined. Accordingly, the requirements are weighted depending on the determined order. Since the total number of requirements is six, the first requirement is weighted with six, the second requirement with five and onwards.

Subsequently, the adjustments and associated costs necessary to achieve the requirements are determined. Since each user has to apply individual adjustments for the intended maintenance application, three general possibilities and the respective costs are provided for each requirement. The idea behind the general possibilities is that a requirement is either fulfilled or not. In the case where a requirement is fulfilled, no further adjustments are necessary. In the case where a requirement is not fulfilled, either the current features can be changed, or new features can be integrated. An overview is shown in Table 4.

Table 4. Adjustment for implementation requirements

Status	Adjustment	Cost	Rating
Sufficient level	None	None	0
Insufficient level	Change current features	Low	1
	Integrate new features	Medium	3

Finally, the total implementation costs are calculated. The basis is the weighting and the rating of the costs for the implementation adjustments. For the calculation, the weighting is multiplied by the rating of the respective requirements and the results are then added together, which is shown in equation 2. The following abbreviations are applied for the clear presentation of the equation: weighting (W), rating (R), implementation costs (IC), skills of employees (SE), acceptance of employees (AE), maturity of technologies and machines (MTM), degree of digitalization (DD), data security (DS) and safety (S).

$$R_{IC} = W_{SE} \times R_{SE} + W_{AE} \times R_{AE} + W_{MTM} \times R_{MTM} + \\ + W_{DD} \times R_{DD} + W_{DS} \times R_{DS} + W_S \times R_S \quad (2)$$

The cost metric, shown in Table 5, is utilized to classify the implementation costs as low, medium, or high costs with the respective rating.

Table 5. Cost metric and rating of hardware costs

Range of rating	Cost metric	Rating
X > 42	High	5
21 < X <= 42	Medium	3
X <= 21	Low	1
X = 0	None	0

4.3. Cost-benefit analysis

The objective of the third step of the DSF-RTM is to compare the total costs and total benefits that arise from the application of the AS based on RT in maintenance.

First, the total costs are calculated. Total costs consist of acquisition costs and operating costs. The acquisition costs include the one-off costs for hardware and implementation determined in the first two steps. The operating costs cover the annual costs for software identified in step 1 and maintenance. The annual maintenance costs are to be estimated by the user of the framework based on the defined cost metric. The maintenance costs consist of the maintenance effort for the hardware and software as well as the implementation requirements including the preservation of the digitalization standard, data security standard and safety standard. In addition, the costs for maintenance personnel are covered. Furthermore, the user of the framework has to define the period of time after which the investment in the AS based on RT in maintenance is supposed to be profitable. The period of time is to be defined in years. In summary, the total costs result from the rating of the hardware and implementation costs as well as the rating of the annual software and maintenance costs for the defined period of time, as shown in equation 3. For the clear presentation of the equation, the following abbreviations are utilized: rating (R), total costs (TC), hardware costs (HC), implementation costs (IC), software costs (SC), maintenance costs (MC) and time (T).

$$R_{TC} = R_{HC} + R_{IC} + (R_{SC} + R_{MC}) \times T \quad (3)$$

Subsequently, the total benefits are assessed. Against the background to design an application-oriented and generic framework, a simple and generally applicable method is established for the assessment of the benefits. The criteria risk, performance and costs are the basis of the method, as they are defined as a balanced set of criteria for the evaluation of assets in maintenance [19,20]. The aim is to estimate whether the application of the AS based on RT has none (rating = 0) or a small (rating = 1), medium (rating = 3) or high (rating = 5) positive impact on the risk, performance, and cost level of maintenance. In summary, the assessment of total benefits is based on the rating of the annual impact on the risk, performance, and cost level of maintenance for the period of time defined by the user of the framework in the calculation of total costs, as shown in equation 4. For the clear presentation of the equation, the following abbreviations are applied: rating (R), total benefits (TB), risk benefits (RB), performance benefits (PB), cost benefits (CB) and time (T).

$$R_{TB} = (R_{RB} + R_{PB} + R_{CB}) \times T \quad (4)$$

Finally, the rating of the total costs is compared with the rating of the total benefits. In the case that the total benefits outweigh the total costs, the investment is considered to be profitable, and the framework can be completed with the fourth step. In the case where the total costs outweigh the total benefits, the investment is considered to not be profitable. A decision has to be made whether a suitable alternative is to be investigated or whether the conclusion is drawn that the investment is nevertheless profitable or no suitable AS based on RT is available and the framework is thus ended. In the case that an alternative is to be investigated, three options are possible to reduce the total costs and thus make the investment profitable. First, the costs for the AS based on RT can be reduced by identifying a less expensive output device, input device, tracking device or development platform (Step 1). Second, the implementation costs can be reduced by making compromises in the adjustments to fulfil the implementation requirements (Step 2). Third, the maintenance costs can be reduced by making compromises in the maintenance plan for the application of the AS based on RT (Step 3).

4.4. Implementation guide

As a basis for the implementation guideline, literature from the field of project management with a focus on technical projects is utilized. In general, five phases are defined for technical projects: initial phase, definition phase, development phase, realization phase and conclusion phase [21].

The initial phase includes the preparation of the project. Initially, a project team is to be set up. In addition, the initial situation is to be analyzed to define the objectives and based on that the tasks of the project. Furthermore, the remaining phases are to be planned in terms of content and time.

The definition phase consists of the identification and the selection of the AS based on RT. The context analysis and the implementation requirements analysis are to be utilized for the identification and the cost-benefit analysis is to be applied for the selection.

The development phase involves the development or purchase as well as the testing of a prototype of the selected AS based on RT. In the case that the results of the testing are not satisfactory, a decision has to be made whether to identify and select another system in the definition phase or to stop the project. In the case that the results of the testing are satisfactory, the next phase is to be conducted.

The realization phase includes the preparation and implementation of the selected and tested AS based on RT into the intended maintenance application. For the preparation, the adjustments defined in the implementation requirements analysis are to be realized. After the requirements are fulfilled, the AS based on RT can be employed in the intended maintenance application. Following the realization, a final usage analysis is performed to identify possible weak points and based on this, to implement improvements.

The conclusion phase consists of a post-implementation calculation to compare the target costs and the actual costs as well as a final report on the project. Furthermore, a task force is to be established for the usage and maintenance of the AS based on RT.

5. Validation

For a first validation, the DSF-RTM is focused on CNC machine tools in small and medium-sized enterprises (SME). Important requirements are in this context the easy and fast applicability, since SME are usually limited in resources, in prior knowledge and time in the implementation of RTM-application projects. In the case study the DSF-RTM framework was utilized to investigate a solution for the execution of maintenance activities on a “EMCO Concept Mill 260” CNC-milling machine with a 20-tool magazine. It is located in a learning factory that is comparable to a SME. The case study is divided into use cases of scheduled and unscheduled maintenance activities. The scheduled maintenance activities consist mainly of relatively simple inspection, cleaning, and refilling tasks.

The result of DSF-RTM framework in this use case of scheduled maintenance activities is that no profitable solution is identified. The outcome of the use case of unscheduled maintenance activities consisting mainly of diagnosis and complex repair tasks is that an MR-based HMD (e.g. a Microsoft HoloLens) enabling remote support is economically viable.

In order to draw further conclusions, the case study is examined whether the DSF-RTM fulfils the two LRs and four

CRs defined in chapter 4 using an expert validation. The first LR is to create a user-friendly framework, which is generally fulfilled with the DSF-RTM. The proposed framework is well structured and supports the decision-making process without being complicated and detailed. The expert had no problems in following the logic of the DSF-RTM. However, the expert suggested as an optimization proposal to introduce norms or standards as an objective reference in the second step. The reason why general definitions are provided and thus a subjective assessment by the user is necessary is that each application has different requirements. As an example, the requirement concerning the degree of digitalization is mentioned. If the maintenance task requires the AS based on RT to display information only to the user, no WIFI is necessary at the point of use. However, if the AS based on RT is required to retrieve real-time information, WIFI is necessary at the point of use. Both cases require a different level of digitalization. Therefore, no generally valid statement can be made as to which standards or norms are necessary. Furthermore, the second LR is that no knowledge of RT is necessary to apply the framework, which is fulfilled with the DSF-RTM. The expert had no difficulty in identifying and selecting the hardware and software components as well as in assessing the impact concerning risk, performance and costs of the AS based on RT on maintenance. The four CRs which require a consideration of hardware and software as well as implementation requirements, a feasibility study and an implementation guideline are fulfilled. Therefore, the case study verifies that the DSF-RTM framework provides support in the identification, selection and implementation of ASs based on RT in maintenance.

6. Conclusion and outlook

This paper presents an application-oriented and framework that assists companies with the identification, selection and implementation of ASs based on RT in maintenance. The developed DSF-RTM framework considers in the first step the currently available and for the maintenance application suitable output devices, input devices and tracking devices as well as development platforms. In the second step, the requirements for a successful implementation of AS based on RT in maintenance are analyzed. The third step includes the economic considerations of the application and the fourth step provides support to realize the implementation. The validation in the use case of the maintenance of a CNC milling machine in an SME environment using RT-based solutions showed that the DSF-RTM framework supports with moderate efforts the application decision. Further research will focus on the application of the DSF-RTM framework on different industries such as the rail industry or process industry. Another aspect to be addressed for future research is to consider country-specificities for further enhancement.

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