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An innovative process to select Augmented Reality (AR) technology for maintenance

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Abstract

Augmented Reality (AR) technology for maintenance aims to improve human performances by providing relevant information regarding both corrective and preventive maintenance. The development of an AR system involves the choice of a hardware, a development software and a visualisation method. These selections are challenging due to the wide choice of services and options available which result in fragmentation: different development processes and different user experiences.

In order to ease the selection of an AR system for supporting maintenance operations, this paper proposes an innovative process. It guides the reader to identify the requirements and the constraints for any specific application through a number of questions developed in this study to help with the selection. This results in suggestions for the selection of the hardware, the development software and the visualisation method. The process is built based on a literature study, grey documents and experts interviews. Future works includes the validation of the selection process proposed in this project. It could be done by comparing the choices made using the proposed process with the choices made by experts for the same case study. Moreover, the decisional process could be extended to face the economical and ergonomics aspects related with the selection of an AR system. It could be done expanding the literature research including studies which investigate into the economical and ergonomics consequences of the application or AR for maintenance.

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Keywords: Augmented Reality, Maintenance, Process.

1. Introduction

The aim of Augmented Reality (AR) technology is to enhance human performances by providing relevant information for a given specific task. AR can be utilised through any type of hardware able to interact with human senses: Tablets, Head Mounted Displays (HMD), Hand-Held Display (HHD), projectors and headphones. The reason for selecting a device rather than another is not always trivial and it relates to the environmental conditions, the users and the processes requirements. In the same way, the software architecture of the AR System might be selected based on considerations which vary among different industrial environments. For instance, while military could prefer to utilize "zero-connectivity" in order to ensure the cyber security, a commercial application could require connectivity for providing remote assistance. Finally, the user interface should be selected based on the user and the process requirements. It has to be mentioned that there is fragmentation between the providers of AR tools (hardware and software). It means that the combination of the devices, the Software Development Kits (SDKs), open-source platforms and the commercial ones available results in a high number of possible ways of developing an AR system, but the advantages and disadvantages are not always clear.

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This paper aims to propose a process that could guide the reader to select its AR system features and capabilities, as well as the development constrains.

Section 2 explains the methodology utilised for building the proposed AR decisional process for maintenance. Section 3 reports the results including an example of the utilisation AR decisional process. Finally, Section 4 covers the conclusions, which includes the discussion and proposal for future works.

2. Methodology

This section reports the methodology utilised for developing the process to select AR technology for Maintenance.

The following objectives have to be reached in order to develop the process:

1) Identifying relevant documents for the project.
2) Compiling AR systems characteristics tables.
3) Analyse tables.
4) Develop a process to select the AR system characteristics.

2.1. Phase 1: Documents identification

The first phase of the project has been identifying relevant applications of AR in maintenance.

A systematic literature review [1] method has been used to answer the research question: how are AR systems selected and developed for maintenance? The databases selected are: Scopus, ScienceDirect and IEEE. The initial string utilised for the searching phase has been: (“AR” OR “Augmented Reality”) AND (“Maintenance”). Inclusion and exclusion criteria have been defined to narrow down the number of articles identified. This approach led to 29 relevant documents as referenced [2]-[30] to answer the research question.

2.2. Phase 2: Compiling AR systems characteristics tables

Phase 2 consists of categorizing the articles collected during *Phase 1* in a form which allows comparison and analysis.

Considering the aim of the project, each document has been screened to find any trends in the correlation between the hardware, development software, visualization method (and user interface) selection and the case studies. It has been done by compiling a table for each article. In the rows are listed the hardware, the development software and the visualization methods; in the columns are reported the description, the motivation statement and the comments. If required, a raw with another relevant feature has been added. In Table 1, provided as an example, a raw with the information about tracking has been added.

The tables have then been reviewed and modified in order to use a similar nomenclature on the cells for allowing the comparison process.

Table 1 Example of table compiled for one article. The article is reported in the top left corner.

Fiorentino (2014)	Description	Motivation Statement	Comments
Hardware	Projector 2.5m cameras	HMD not well accepted by the users: imbalance and weight; limited FOV; visibility of digital overlay.	
Development Software	Unifeye Engineer Visual basic	for industrial applications	
Visualisation Method & User Interface	animations text images		Bluetooth headset and speech recognition not acceptable due to the number of mistakes
Tracking	Marker-based (4x40mm + 1x140mm)	robust and accurate tracking	useless if not calibrated

2.3. Phase 3: Analysis

As a result of *Phase 2*, 29 tables, like Table 1, have been built. *Phase 3* consists in comparing the tables. It has been done cell by cell with particular emphasis on the “motivation statement” column mentioned in Sec. 2.2. When the content of the same cell of the different tables were in agreement, the cell has been colored in green, when in partial agreement in yellow, when in disagreement in red.

As outcome of this process, the main reason for the selection of each parameter can be listed.

2.4. Phase 4: Develop decisional process

This phase aims to develop the process for selecting a specific AR technology. Based on the analysis made in phase 3, the author decided to develop four questionnaires (Sec. 3) and to provide the charts (Fig 1-4) for reading their results.

Firstly, based on the tables analysed in Phase 3, 93 questions have been developed to assess the AR system requirements. It has been noticed that each answer can affect more than one choice (hardware, development platform and visualization method). Moreover, in order to ease the application of the process, the author aimed to simplify the questionnaire narrowing down the number of questions to 30 and dividing them by topic. The final output are 4 different questionnaires: one for assessing if AR could improve the operator performance, three for assessing respectively hardware, development platform and visualization method. The Nr. 4 questionnaires are reported in Sec. 3. The answer to any question would be a number from 1 to 10 respectively "completely agree" and "completely disagree". These questions are the outcome of the correlation between the motivation for making a choice and the choice itself. For instance, if it has been proven through *Phase 3* that Head Mounted Displays (HMD) are utilized when the task duration is between 30 and 60 minutes, the question would be: does the task last more than 30 minutes? For a task that lasts on average 28 minutes, the answer would be 7-8 (disagree) depending on the variance of the phenomenon.

The results of these Nr.4 questionnaires answer will be than analysed through the Nr.4 charts below (Fig.1-4). The average answer of each table corresponds to a specific choice.

These charts have been designed considering the major trends and correlations found in the literature.

Once the average scores have been compared with Fig 1-4, a feasibility check is required to assess the compatibility between hardware, development platform and visualization method. It has to be done case by case by checking the latest update from the provider and using the technical datasheet of the hardware and the development platform.

3. Results

The result of this study is the process for selecting the AR technology for maintenance. The process consists in: nr. 4 questionnaires (Tables 2 - 5) and nr.4 charts (Fig.1-4) for understanding the questionnaires results.

The questionnaires are designed for assessing the AR system requirements for a specific maintenance case/task. For more than one application, it is suggested to apply the process multiple times.

The answer to each question has to be a number 1 to 10 where 1 means "completely agree" and 10 means "completely disagree". Following the nr. 4 questionnaires.

Table 2. Questionnaire for assessing whether AR is required/feasible or not.

Questions	Score (1-10)
the task does not require concentration	
the duration or error rate variances are less than 10% among different operators	
flexibility among operators is not required	
the system to be maintained is complex	
live data is not required to perform the task	
the cost of maintenance is clear	
maintainers do not follow a standard procedure	
the maintainer carries out the same operation daily/often	
the operation is not in a remote location	
The object to be maintained is subject to degradation	

Table 3. Questionnaire for assessing AR system Hardware

Questions	Score (1-10)
the task lasts more than 30 minutes	
two hands are required to perform the task	
the task is not in a narrow space	
the task does not require wide FOV (field of view)	
the task involves flexible objects (hoses, wiring…)	
the location of the maintenance is remote	
the operation does not require gloves, helmet or glasses	
the task involves geometric alignment	
the task requires to connect the object to a computer	
cybersecurity and privacy are major drivers during the operations	
the environment is wet or hot or extreme	
The object to be maintained is subject to degradation	
the color/material and lighting conditions can vary on the object	
the operator position is fixed during the operation	
the task involves liquids	

Table 4. Questionnaire for assessing AR system Development Platform

Questions	Score (1-10)
the location of the maintenance is remote	
the task requires to connect the object to a computer	
cybersecurity and privacy are major drivers during the operations	
the color/material and lighting conditions can vary on the object	
live data is required to perform the task	
maintainers follow a standard procedure	
the operation is in a noisy environment	
the maintenance database has to be updated after the task	
the operation is fail-proof	
CAD of the object to maintain are fully available	

Table 5. Questionnaire for assessing AR system Visualisation Method

Questions	Score (1-10)
the location of the maintenance is remote	
the task requires to connect the object to a computer	
is cybersecurity a major driver for systems selection	
the operator has been trained to perform the task (qualified)	

the operation is in a noisy environment
the maintenance database has to be updated after the task
the operation is fail-proof
the task lasts less than 30 minutes
two hands are not required to perform the task
the task is not in a narrow space
the task does require a wide FOV (field of view)
the task involves flexible objects (hoses, wiring…)
the operation requires gloves, helmet or glasses
the task involves geometric alignment
the time or error rate variance is more than 10% cent among different operators
flexibility among operators is required
the system to be maintained is complex
the design of the components can change

The nr.4 questionnaires are specifically designed to address the AR application in maintenance hence are not suitable for other fields of application (marketing, entertainment, health).

Even though some choices could appear obvious for someone that has been previously exposed to the AR technology, they are not for anyone. The questionnaires have been designed for non-technical person, with a knowledge regarding the maintenance operation. It has to be compiled considering a single maintenance operation. If more than one operation should be supported by the AR system, it would be good to compile the questionnaire for the main activities and then compare the results.

The scores of the questionnaires will then be analysed through the charts in Fig 1-4. It should help the reader understand whether AR should be utilized or not and which hardware, development platform and visualization method should be selected. Even though the selection is made using an average value, all the figures (1-4) show a trend in the selection. It does not mean that it is always possible to identify only one parameter which affects the choice. For each selection the author identified the trends and designed the questions in a way that the answer score would be increasing in the same direction.

Fig.1 is the chart for understanding whether AR could or should be implemented or not. The number to utilise is the average of the scores of Table 2. Fig. 1 has been built considering the average between two trends: the feasibility and the usefulness. Most of the figure implies a situation of uncertainty. This is due to the fact that it is not easy to find any AR application which is undoubtedly useful and at the same time extremely easy to develop and update.

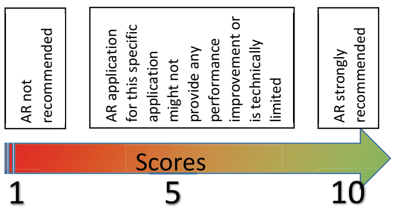

Fig. 1. AR decisional chart.

Fig.2 is the chart for selecting what kind of Hardware/Device should be implemented. The number to utilise would be the average of the scores of Table 2. This chart does not get into the detail of the different devices available. Currently the market of wearable technology and augmented reality is rapidly evolving hence the author intent is to provide an insight of which of the main stream of hardware should be applied for the chosen case. For instance, despite the current technology, the category of HMD would always be more or less suitable in some specific cases. Fig. 2 has been built considering mainly two trends: the flexibility and operator needs (requirements, safety).

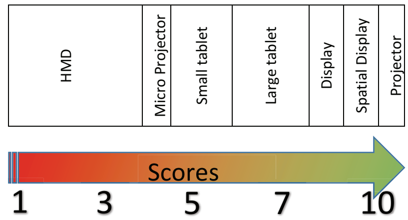

Fig. 2. Hardware decisional chart for an AR system.

Fig.3 is the chart for selecting what kind of development platform should be used. The number to utilise would be the average of the scores of Table 4. For the development platform selection the author decided not to give a specific name/brand, but to identify the main streams. It is relevant to consider that, the main key for this choice resides in the following two: the company capability and requirements under the IT point of view; The AR system complexity

It is obvious that it is always feasible to develop a software starting from scratches and using a very "low level" programming language. It could be useful, on the other side, to rely on a commercial platform which allows the internal IT department of a company to update and modify the AR tool at their convenience.

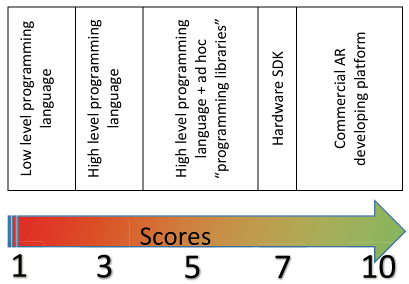

Fig. 3. Development platform decisional chart for an AR system.

Finally, Fig.4 is the chart for selecting what kind of visualization method should be implemented. The number to utilise would be the average of the scores of Table 5. From the left to the right, the author put from the most complex visualization methods, to the easiest. The drivers for this selection are the complexity of the task and the maintainer requirements. As for the previous figures, also in this case the selection will be a tradeoff among the drivers hence, for instance, if the task is very complex but the operator has been trained and carries out the operation daily, there would be no need to provide all the different kind of contents. It would add a not required complexity to the AR system.

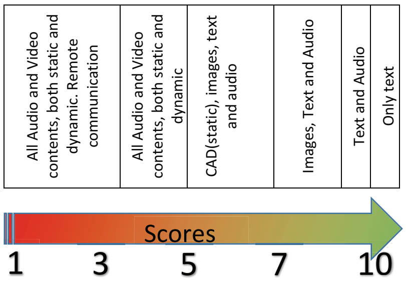

Fig. 4. Visualization method decisional chart for an AR system.

3.1. Phase 3: Process application example.

This subsection reports an example of the application of the process designed in this paper. Firstly, the maintenance operation will be described. Then the AR system selection will be made based on the author experience.

The maintenance case is the change of a brake of a commercial car made by a mechanic in his floor shop. It is a standard operation carried out in a static location which implies the utilization of commonly available tools. It is a high occurrence operation and its variance in terms of time and error rate is very low. No live data from sensors is needed and the environment can be considered noisy and hazardous. The object to be maintained does not change its characteristics but the brake is subject to degradation.

For this specific case, the average scores for table 2-5 would be respectively 3, 4, 8 and 8. Comparing them with Fig. 1-4, it means that AR is not strongly recommended, an HMD would be suggested, commercial platform should be capable to address all the requirements of the development phase and few contents would be required as visualization method.

It has to be mentioned that the validation of the process proposed in this project has not been carried out. The example is provided to show the utilization of the process proposed and the result is based on the author experience in maintenance and AR.

4. Conclusions

This paper presents an innovative process for identifying whether or not AR is recommended and what hardware, development platform and visualization method should be selected for a specific maintenance task. The novelty is that the author is providing a tool which allows non-experts to take a top level decision for selecting an AR system.

The author believes an effort should be put in providing clear methodologies for both companies and academy, to better understand how and where AR should be used.

The validation of the process has to be made. It could be done by mean of survey and questionnaire. Experts could been put in front of the selection of the AR system based on different case studies. Their choices would then be recorded and compared with the outcome of the same selection made by non-experts with the use of the proposed process.

Other future works includes the implementation in the process of a tool for assessing the economic and ergonomics aspects of the AR application. The tool could be developed utilizing the same methodology described in this paper hence based on literature and validated through the comparison between the experts selections and the process selections.

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