Using AR Interfaces to Support Industrial Maintenance Procedures

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***Abstract*—Industries are becoming more and more digitized to better implement intelligent and predictive maintenance support systems, aligned with Industry 4.0, which requires the progressive digitization of data collection and processes. Maintenance interventions, in an evolving technological context, are increasingly more complex and difficult for technicians to perform. In these environments, the use of Augmented Reality (AR) to help assist and guide in the maintenance operations, can accomplish a considerable gain in productivity. AR allows to superimpose information objects in real scenes, such as text, images, audiovisuals, and 2D/3D model animations, making available contextual information about the process, based on location and perspective. This paper describes the design and implementation of a prototype augmented reality application to support maintenance tasks inside a metal stamping production unit, that produces components for the automotive sector. It aims to train and guide personnel during the maintenance operations, and offering an extra channel to reach expert help.**

Keywords: Augmented Reality, Maintenance operations, Industry 4.0.

I. Introduction

Across the years, the manufacturing industry has evolved, forcing all intrinsic and related departments to evolve as well. A key area that have evolved significantly is maintenance. Maintenance is a crucial issue to ensure production efficiency, since unexpected disturbances results in a degradation of the system performance, causing the loss of productivity and business opportunities, which are critical to competitiveness. Nowadays, the industrial maintenance paradigm is mainly reactive and preventive, being the predictive strategy only applied for critical situations. However, the maintenance paradigm is changing and industrial maintenance is now understood as a strategical factor and a profit contributor to ensure productivity in industrial systems [1], [2]. This shift in the maintenance paradigm has led to the research and development of new ways to execute maintenance by considering the operational state of assets and enabled the development of new maintenance approaches, such as the the condition based maintenance (CBM), and the Prognostic and Health Management (PHM) [3]. In its broad sense, these approaches apply data analysis techniques to the information produced in the shop floor processes to detect anomalies in the assets' behavior. Thus, having in mind the improvement of the performance of the production process, this work aims to develop an intelligent and predictive approach for the industrial maintenance, aligned with the Industry 4.0 principles, that considers advanced analysis of the data collected from the shop floor to monitor and earlier detect the occurrence of disturbances and consequently the need to implement maintenance actions. This approach extends PHM and CBM maintenance approaches by considering machine learning and augmented reality technologies to support maintenance technicians during the maintenance interventions by providing a guided intelligent decision support articulated by the use of human-machine interaction technologies.

The Maintenance 4.0 project main goal is to develop an intelligent and predictive approach for the industrial maintenance, aligned with Industry 4.0 principles, where maintenance interventions are generated according to analysis of collected data which tracks the industrial process state. Usually, these interventions are performed by trained personnel applying established procedures in relatively static and predictable environments. These procedures are normally organized into sequences of tasks performed in a specific location. This scenario creates the base to apply technologies to digitally assist an operator in the maintenance intervention. Maintenance sequences can be hard to perform since they require to first position a given task in a location furnished by the model description and then correctly identify this location in the physical world. This is further enhanced when maintaining complex systems, such as those found in industrial domains. On the other hand, complex systems may be particularly difficult to maintain since they involve complex sequences of steps that have to be made involving random objects distributed over a given area. Maintenance operations represent an opportunity for the application of Augmented Reality (AR) technologies [4]. AR allows the user to see the real world, augmenting it with superimposed virtual data, including images, text instructions, audiovisuals or animated 2D/3D models. The paper explores the use of AR to assist maintenance interventions in industrial contexts as a response to an intelligent and predictive system that delivers flow diagrams of maintenance procedures. It experiments the use of tablets and Head Mounted Devices

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(HMD) in guiding an operator in a maintenance operation which involves location, sequential task accomplishment, and procedure guidance. The developed AR system was implemented in a metal stamping production unit, that produces components for the automotive sector, the Catraport industry.

II. Related Work

A. Maintenance in Industrial Scenarios

Maintenance is a set of tasks whose objective is to maintain the equipment and all other related physical assets in the desired operational state within a given economic and business context. This includes all the engineering decisions required to optimize operations in relation with: productive capacity, production quality, failure rate and response capabilities. Optimization must be attained with a minimum amount of resources while ensuring the safety of the machine operators. Maintenance has evolved from simple techniques such as visual inspection, using physics based models that describe the components' mechanical behavior, to more sophisticated methods based on signal processing, pattern recognition, and empirical data based prediction and classification models. Maintenance can be characterized according to its function:

- Detection: is the identification of failure when it occurs (or is about to occur). The aim is to quickly terminate operation in order to safeguard operators and avoid further damage;
- Prognosis: is the prediction of failure within a given period of time. Usually a probability of failure is included;
- Diagnosis: identifies the failing component and/or the root cause of the failure. Empirical models, which may also include domains specific knowledge, can guide the user in diagnosing the problem. Another approach that can provide benefits, can be based on artificial intelligent tools such as knowledge-based expert systems.

B. AR for the Manufacturing Industry

Since maintenance tasks can be very complex and hard to learn, the industry has been undertaking on systems with augmented reality giving the operator more practical and convenient information.

Following the study of Paelke [5], GUI (graphical user interface) are prevalent. With these GUI interfaces the operator can manipulate, interact and get real-time feedback on what is happening. Just like interfaces, the devices where these interfaces are exposed have also experienced a constant evolution. Mobile devices are now part of our daily lives which gives us the opportunity to adapt them to the needs that exist for different maintenance systems. Multi-touch interactions and responsive layouts are the major advantages of using these devices. These new techniques go through gesture bases interaction, the use of virtual reality and augmented reality.

According to the authors in [4] Augmented Reality is a variation of Virtual Environments (VE) or Virtual Reality (VR) as it is most commonly called. His studies suggest that augmented reality systems have three main characteristics: combining the real world with the virtual world, real-time interaction, that is, it is possible to visualize the changes made at the moment they are executed and, finally, visualization and interaction of 3D context. These systems can be developed and used in various types of displays such as head-mounted displays (HMDs), hand-held displays, see-through displays or projectors.

C. AR Applied in Smart Manufacturing

In [6], it was implemented a markerless AR system combining Kudan SDK with the Global Positioning System (GPS) technology. One important feature in Kudan SDK is its simultaneous Localisation and Mapping (SLAM) tracking technology. Being the main rival of Vuforia, this SLAM feature distinguishes both of them by making the Kudan SDK a good choice and path to follow when developing a markerless tracking system. Side by side with the GPS it provides the system the ability to get, process and analyze images. By mapping the environment and understanding locations this system is capable of, accurately, execute previously determined functions set by the programmer when certain environmental conditions are gathered. Despite all the good things Kudan SDK has to offer, this AR markerless system is not suitable for indoor environments since it uses GPS as the source of localization information.

In [7], presented a markerless AR system by combining deep learning object detection and spatial relationship with interaction and geovisualization in uncontrolled outdoor environments as a goal. They achieved a system that can adapt to different challenging outdoor conditions such as, motion blur, rotation, occlusion, scales, etc. However, even being well developed and capable to perform as it should for an AR application, GPS systems all have a lot of trouble to work properly indoor which also makes this system not suitable for industrial environments.

In [8], Microsoft HoloLens smart glasses were used in order to implement an marker based AR system prototype to assist industrial maintenance tasks. This application allows the operator to perform any maintenance procedure without prior knowledge, which means that with this technology operators are able to take care of any type of maintenance task for the first time without having to study how the machine works or how to repair it. With a hands-free system, operators have to go through a series of steps with visual support by the HoloLens in order to complete the process. This tutorial based application in AR is the scenario of future Industry 4.0 era.

In our solution, a marker based AR to enable maintenance and training using a tablet device is proposed. We also describe the first experiences of a version targeted at the HoloLens Glasses, providing the user with a hands free hands-free assistant.

III. System Architecture

This section describes the system architecture for the intelligent and predictive maintenance system (details can be found in [9]), along with the maintenance process that feeds the User Interface for the maintenance interventions.

A. Overall System Architecture

There are several technologies that facilitate human work, such as, augmented reality (AR), virtual reality (VR) and intelligent personal assistant (IPA). The IPA is an application that helps the operator in the interaction with the machines or computers and to perform tasks or services. The system architecture of created IPA is shown in Figure 1.

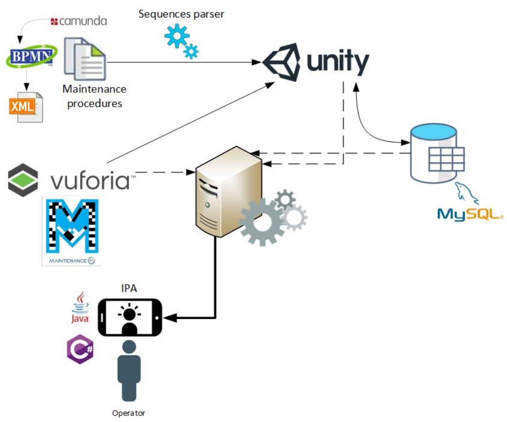

Figure 1: IPA system architecture.

The IPA consists on the following modules:

Maintenance procedure: The maintenance procedures were specified using Business Process Model and Notation (BPMN)s according to the needs of the Catraport factory. Under each procedures there are specific tasks that are guiding the user through the maintenance interventions.

User Interface: To create a user-friendly interface for maintenance tasks application was used Unity platform. This real-time platform allows to build instant applications that are small, light and fast. Unity supports both 2D and 3D development with features and functionality for specific needs across genres.

Monitoring: The application uses the identification of marks created with Vuforia to display a web view by the tracking of the target image.

Data Collection in Database: To make the application and the process of work more fast and easy to use, all the data are stored in MySQL database. The application, during the implementation of maintenance procedures, send the data to the database about the user that is using the application, current procedure, response from the user, the beginning and end time of the procedure and also date and time. Collection of this information is made for further data analysis for earlier detection of failures.

B. Maintenance Process

The Dynamic Monitoring module is responsible to apply the generated rules to the collected data, supporting the visualization of the machine health along the time but also the detection in advance of needs for maintenance interventions as depicted in Figure 2. The Intelligent Decision Support (IDS) is responsible to provide guidance to the technician during the execution of maintenance interventions. It furnishes a description of the process to be done together with any media needed to help guide the technician during the intervention.

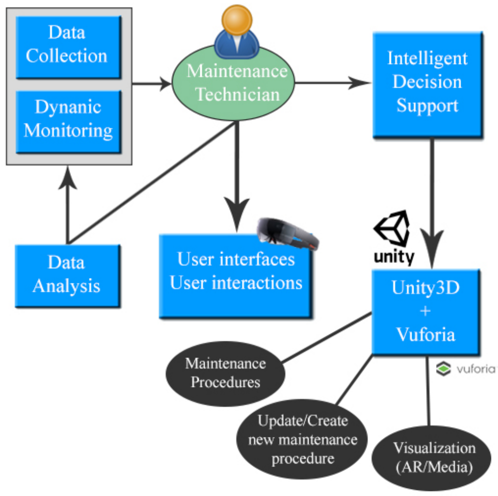

Figure 2: Maintenance process.

C. Process Diagrams

To provide an intelligent support for technicians during the maintenance interventions was necessary to have a sequence of maintenance procedures which guides the user during the work process. To describe and create a model of the maintenance processes was used BPMN standard. This standard allows to represent maintenance procedures by graphical notation which is understandable by all users and technical developers responsible for implementing the technology that will perform those processes. For further data processing was needed a transformation of BPMN diagrams in to the XML file. This process was made Camunda platform, which is automatically translating the diagrams into XML. To display maintenance procedures step by step in the application, it was created a C# dictionary of tasks based on processing transformed XML data, thereby displaying necessary tasks on Unity interface. During the maintenance procedure, the user has two options of answer on the questions, represented by buttons “Yes” or “No”. Depending on each answer the sequence of the tasks can be changed. The sequences validation is also verified by the created script.

IV. Development of UI to Guide Maintenance Processes

The user interface (UI) guides the technician to accomplish the maintenance task sent by the IDS. It uses the Augmented Reality paradigm to guide the operator through the maintenance process by positioning the operator at the procedure location and guide the task with media explaining the several steps involved int the process. The following section describes the system to assist the maintenance process before and during its execution.

A. Hardware and Software Tools

The developed system uses two hardware mobile devices to support the maintenance tasks, namely a head-mounted display, Microsoft HoloLens, and a mobile Android Tablet Lenovo 10". The software used consists in the Vuforia AR SDK, to develop a marker based application, and Unity3D. Unity is a cross-platform game engine developed by Unity Technologies which gives users the ability to create game applications in 2D and 3D. The engine offers a primary scripting API in C# for programming purposes that facilitates the development of spacial environment applications. Vuforia is an AR software development kit (SDK) that allows the creation of AR marker based application which operates in mobile devices. It uses computer vision technology to recognize and track planar images, also known as image targets, and simple 3D objects. This image registration capability enables developers to position virtual objects in the real world that can be viewed through the camera of a mobile device giving us the chance to easily reach augmented reality. Unity integrates the Vuforia Engine, making it even easier to create cutting edge augmented reality experiences for both hand-held and headworn devices.

B. Design Requirements

The design principles to create UIs in industrial environments should always follow ergonomic guidelines established for designing software and hardware systems [10]. Specifically the following guidelines should be taken into account in designing a interface:

- The field of view should be as wide as possible. 30º (horizontally) are usually the minimum recommended for providing a good user experience.
- The AR interface should be as light as possible, since it has to be worn during the whole day.
- Ideally, the batteries should last through the working day.
- Optical and retinal projection should be used, since video-based display technologies incur in delays that harm the user experience.
- Voice-based interaction is recommended to enable hands-free operation, although voice processing has still to be improved to work properly in noisy industrial environments.

C. UI System Architecture

The systems receives the maintenance task and allows the operator two operations as depicted in Figure 3. The first conducts the user to a training process where the task can be repeated as many times needed to acknowledge the several steps involved. The second conducts the user to the maintenance process guiding throughout every step included in the maintenance task. As each step of the maintenance is done, a list is maintained for the operator to consult and backtrack it, if needed.

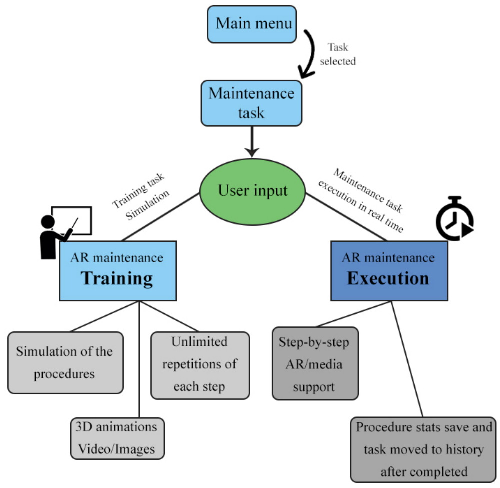

Figure 3: UI System Architecture.

D. Visualization Design

Each operator have their specific tasks, however, our application is ready to support all the procedures that are not yet concluded. For this, in the main interface after notifying the system which operator is using the application the user is able to decide between a few courses of action. A list of undone procedures is displayed in the central field of view of the user since it is the main goal of the application. After clicking one of the procedures shown in the mobile device the operator has choose between training or execution. The training mode consists in a simple practice mode where the user has to follow a series of steps similar to the ones he has to execute in the machine when taking care of any maintenance procedure. However, while in the executing mode the user has the AR support while he proceeds to perform the actions in the machine itself, in training he simply follows the steps previously created and implemented on the system and watch them being performed in the mobile device as an exercise. This mode is specially a good asset and also recommended for those who are doing some sort of maintenance procedure for the first time so that this operator can take less time than usual learning the basics about the machine and feel more comfortable and supported when performing the given tasks. There is an easy access to the history of the user's finished maintenance procedures. This interface allows the user to check which procedures are already completed by him and can also verify the respective stats from the procedure process such as: date, time, name of the operator, duration of execution, how many times this process has been completed, etc. Since we are dealing with maintenance procedures it is expected that the processes can be repeated somewhere in the future so, by scrolling through the history of completed procedures, a training option is also available so that the user can exercise and redo as many times as he want the same tasks in order to make easier when the time comes.

Furthermore, support is also present in the system in case

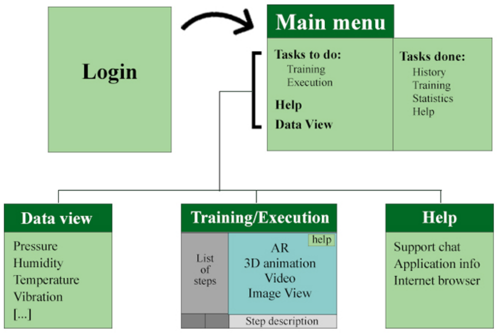

Figure 4: Visualization Design.

that the operator needs some sort of help, either at a technical level to aid the user completing any procedure and support about the application as well.

E. Implementation

After completing the authentication step (login) the operator is taken to the main menu and chooses between training, maintenance or monitoring mode. By clicking on training, the application displays a list of tutorial (step-by-step) guides for each available maintenance tasks. Media such as videos, images and 2D/3D models are provided by the system to support operators during their tasks and procedures. For every step, the type of media is logically determined according to the need of each task. After finishing all steps, the user is taken back to the main menu and the completed task gets a different highlight color in the procedures list so that its conclusion remains visible for the user however it can still be redone.

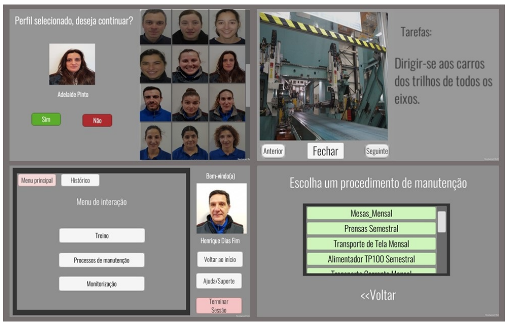

Figure 5: System UI.

A maintenance list of procedures is displayed when this mode is activated in the main menu. With the usage of the Vuforia mark/image tracking, a process, once chosen from the list, is only started when the user is in the beginning point set by the Vuforia mark technology that acts as an image target initializing the procedure. After completing a certain step the user continues to the next one by clicking a continue button or using voice commands. The progress of the procedure is always visible since the user visualizes all the steps done, remaining ones and, of course, the currently active which is highlighted to be more clear for the operator to locate himself during the procedure. In order to find a certain machine element that is outside the limited field of view, 3D animations were implemented in the system to show the user where he should go to perform any given task, this way the distance limitations regarding the view distance for the camera to recognize the marker and trigger any previously implemented action are minimized since the operator can go straight to the point where the 3D animations guides him. In case this process fails a support/help button is also active and ready to be used anytime when a problem arises which will let the user communicate with an expert.

Figure 6: System UI/UX for maintenance procedure.

In addition to maintenance and training/support it is implemented in the system a monitoring window. When accessed, this mode provides the operator all the data (pressure, humidity, temperature, vibration, etc.) available about certain machine. As a start point the AR camera takes place in the scene and, as soon as the user points the device into a Vuforia mark positioned in the desired machine, this will trigger a page in the application with all the data about it. Given this information the operator is able to detect any flaw and fix before it spreads and becomes a larger problem (preventive maintenance).

Finally, each user have access to an history window when they can view stats such as, which procedures they have completed and time spent on each task. This information is loaded from a database that holds receives and save useful data.

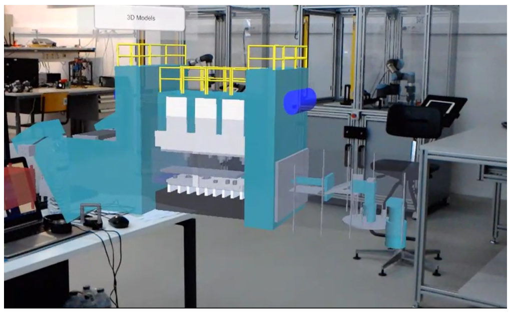

Figure 7: HoloLens implementation.

As seen in the Figure 7 above, the same system developed in the tablet hand-held version of the application was also implemented in the Microsoft HoloLens as a head-worn, in other words, a hand free version.

V. User Experience Evaluation

In order to validate the system, a set of user tests was carried out to gather quantitative usability metrics. In particular, the System Usability Scale (SUS) questionnaire [11], [12] translated to European Portuguese according to [13] was used. The main goal of this evaluation was to understand how, in a real-life context, users/operators would react and experience our application. The users made use of the prototype application to conduct AR assisted interventions in an industrial metal stamping unit.

Table I: SUS Survey Results

Item	Average
I think that I would like to use this system frequently	4.66
I found the system unnecessarily complex	2.08
I thought the system was easy to use	4.75
I think that I would need the support of a technical person to be able to use this system	2.75
I found the various functions in this system were well integrated	4.50
I thought there was too much inconsistency in this system	1.41
I would imagine that most people would learn to use this system very quickly	4.50
I found the system very cumbersome to use	1.41
I felt very confident using the system	4.50
I needed to learn a lot of things before I could get going with this system	1.41

SUS Score = 84,8

User evaluation was performed with 12 subjects, with 7 ♂and 5 ♀. The users had an average age of 28 with their ages ranging from 19 to 43 years old. The SUS consists of a 10 item questionnaire with a five-level Likert Scale with options ranging from "Strongly agree" to "Strongly disagree", with a numerical correspondent from 1 to 5 points. The ten item questionnaire, along with the average scores for each item, is illustrated at Table I. The global SUS score was 84.8 which corresponds to a qualitative close to "Excellent", according to [14].

VI. Conclusions

In a context of digitized industries the role of maintenance interventions is important to achieve an increase in productivity. This paper presents the development of UIs to support the maintenance interventions in an industrial environment using the Augmented Reality paradigm to assist the operator performing the maintenance task. The application makes use of procedure knowledge to lead the operator in the task sequence. It describes the overall system that supports the machinery interventions and describes the considerations involved in the several phases of UI development. Results from an user study exploring the use of a prototype AR application to support operators doing interventions in an industrial metal stamping unit are presented. The prototype tablet AR application allowed individuals to locate and perform tasks in a maintenance sequence using an assisted system. It was favorably received by users following a SUS user experience questionnaire which resulted in a very positive evaluation.

Future work includes the development of an improved UI for the tablet application based on the user feedback. Another objective is to improve the Hololens application to turn it into a more immersive experience. The support of more media types, such as voice, is also aimed in order to enrich the system with other means of information assistance.

Acknowledgments

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