STARMATE: Using Augmented Reality technology for computer guided maintenance of complex mechanical elements

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Abstract. This paper presents the project STARMATE, funded by the EU (IST-1999-10202), which aims at specifying, designing, developing, and demonstrating a prototype allowing computer guided maintenance of complex mechanical elements using Augmented Reality techniques. The system will provide two main functionalities: User assistance for achieving assembly/de-assembly and maintenance procedures, and workforce training of those procedures.

The system is dedicated to applications where access to conventional paper or other documentation is cumbersome and aims at integrating digital technical manuals, construction files and maintenance procedures seamlessly into the workplace. It will rely on Augmented Reality techniques, which is a growing area in Virtual Reality research. The idea of Augmented Realtiy is to combine a real scene, viewed by the user, with a virtual scene, generated by a computer, augmenting the reality with additional information. A multi-modal concept is basis for the interaction with the system.

1 Introduction

The main idea of the STARMATE project is first to provide assistance to a user who has to perform demanding working processes on complex mechanical elements and second to increase the skills of a user to perform such processes by passing him through training scenarios. In contrast to other areas, where new technologies replace manpower, this concept enables workers to perform tasks, normally requiring a higher level of qualification, and even allow them to reach such a higher level of qualification by providing a more evolved implementation of the well known principle *learning by doing.*

Section 1.1 introduces a typical scenario designated in this project, to allow the reader a better insight to the following descriptions of the system. The technical components of the system are presented in section 2, whereas a rough overview of the software components is given in section 3. Section 4 delivers insight, how to use STARMATE as an end-user. End-user means in contrast to the term user (the one really working with the equipment) the company using the system. More information on the partners of the STARMATE consortium and the demonstration of the system in real industrial environment is given in section 5. Finally, experiences, chances, challenges and risks of this project are discussed in the conclusions.

1.1 A Typical Scenario

To get an impression how the STARMATE system works, the following scene is presumed: A user, equipped with a so-called **Head Mounted Display (HMD)** in see-through mode, a **microphone** and **headphones**, has to perform some tasks on a mechanical element (see Figure 1). The see-through mode of the HMD allows the user to see the real image of the scene, which is augmented by a computer generated virtual image, containing additional information. Figure 2 shows this additional information: the suitable wrench to the corresponding highlighted screw. The screw is highlighted even, if the user moves his head, as long as the screw is in his view. This kind of augmentation is characterized as registered to the mechanical element. Furthermore there will be augmentations registered to the world (e.g. technical documentation on the equipment), to the user (when the user moves, the augmentation 'follows') and remanent restitutions (is fixed in the field of view of the user, e.g. error messages and specific symbols).

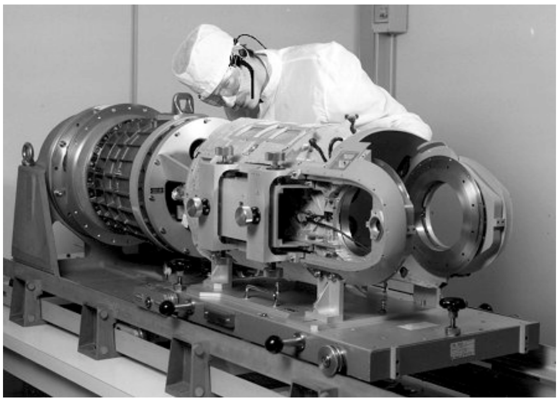

Figure 1: user working on a mech. element

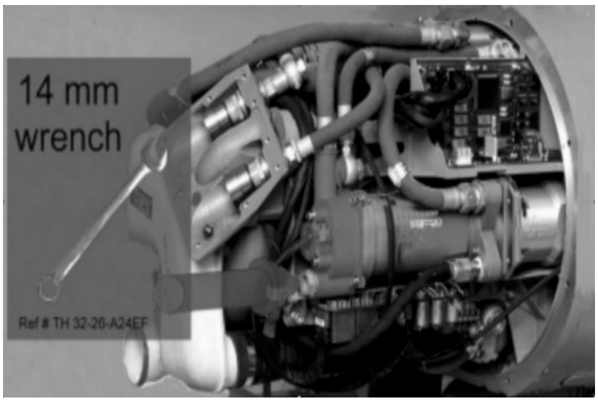

Figure 2: augmented view of the user

Apart from **virtual objects** and **graphics**, **videos** and **audio augmentations** will support the user. The communication of the user with the system is based on a **multi-modal interaction** concept, described in section 3.2.

1.2 Augmented Reality

For understanding the principle of STARMATE it is important to get familiar with the keynotes of the technology behind the system: **Augmented Reality (AR)**. While Virtual Reality techniques are already utilized in many applications Augmented Reality techniques are still relatively unknown.
The early ideas of Augmented Reality go back to the sixties, but it took about 30 years until AR slowly found its application outside research laboratories. The main idea of AR is to combine a real scene, viewed by the user, with a virtual scene, generated by a computer and augmenting the reality with additional information. The ultimate goal is to create a system such that a user cannot tell the difference between the real world and the virtual augmentation in it.

Various applications of AR exist, addressing for example Medicine [3], [9] and [11] repair of copier machines [8], installation of aluminium struts [14], complex maintenance and repair tasks [3], guided assembly [13], electric wire bundle assembly in airplanes [5], insertion of a lock into a car door [10], interior design [12], or special effects [4]. However, all these applications are somehow demonstrators and proof of concepts. A real transfer of AR-technology to industrial use is still to be done and could be the result of the STARMATE project. Another project in the industrial context is Arvika [1].
Currently, the most difficult problem in AR is the **registration** issue [2]. The real and virtual objects must be properly aligned with respect to each other, or the illusion that the two coexist will be compromised.
In contrast to virtual environments, visual AR applications require a much higher registration precision, because the human eye is very sensitive to a mismatch between virtual and real objects [3]. Foundation for a good registration is the **tracking**, that means the determination and tracing of the position and motion of the user. Existing tracking devices are limited, either in their range capability (i.e. mechanical or ultrasound tracker), or because of interference with metallic objects (i.e. magnetic tracker).
The main part of the STARMATE tracking system consists of an **optical infrared stereo tracker**, similar to [6], which will possibly be combined with an **inertial tracker** to overcome some weaknesses of a full optical solution.

2 Technical Components Of The System

STARMATE system splits into three parts as illustrated in Figure 3. The first part of the system is the **heavy computation unit (HCU)**. This unit is remote from the user and consists of a set of three computers, cameras at the ceiling for the optical tracking and other hardware constituting the equipment's brain. The cameras are equipped with infrared filters and the objects to be tracked, e.g. the user, are provided with small markers, reflecting infrared light, emitted by an infrared light source. By processing those camera images, a reconstruction of 3D poses is enabled.

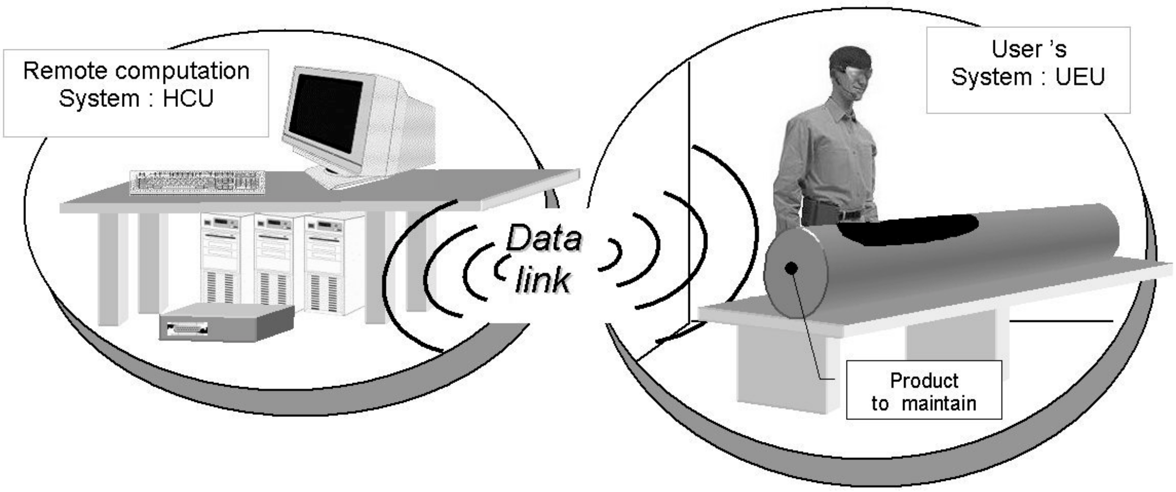

Figure 3: STARMATE system

The second part of the system is the **user's equipment unit (UEU)**. It mainly composes of semi transparent goggles (HMD) allowing to see real scenes and to display visual elements over them, a microphone allowing the user to control the system through a remote voice recognition system, headphones allowing the system to provide audio messages to the user. Instead of a physical pointing device allowing the selection of items in the virtual and real world, a **wireless** solution is preferred: a **virtual pointing device (VPD)**. The VPD is a ray with its origin between user's eyes, pointing into the direction of selectable objects (see Figure 4). The advantage of such a pointing device is, that both hands of the user are free for working all the time and selection can be controlled by head movements and voice commands.

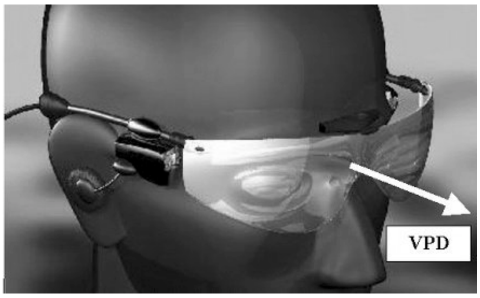

Figure 4: a wireless solution - the virtual pointing device

The third part of the system is constituted by the means enabling the UEU and HCU to communicate, referred to as the **datalink**. Several different signals have to be transmitted between UEU, HCU and the cameras of the tracking system. Various possibilities of datalink configurations are considered, e.g. for the visual augmentations a transmission as VGA signal on copper cables, which is the actual solution, a transmission on fibre optic after conversion from VGA to PAL or a transmission as "high level" data on wireless link. Furthermore audio signals and data from the inertial tracker have to be transmitted, as well as the signals from the tracking cameras and the their synchronization signal.

3 Software Components Of The System

The necessity of **real time use** of STARMATE equipment has a strong impact on the design of its architecture. In addition, the complex tasks fulfilled by the system, and its mode of development (in a consortium), impose a **modular design**. This is the reason why STARMATE architecture is organized following the main functions of the system and is therefore composed of the modules, illustrated in Figure 5 and described in the following subsections.

3.1 Supervisor (SUP)

The supervisor is the orchestra conductor. This module serves for scheduling and synchronizing the various dataflow of the system and manages the different modules as well. The SUP is composed of two processes, one to coordinate the commands and data received from the different STARMATE modules, and another for the real-time data flow between PAM and RM, transmitting the user pose and the equipment pose.

3.2 Command Interpretation Module (CIM)

The functionality of CIM is to convert a multi-modal command coming from two different modalities (speech and pointing device) into one single command, that can be processed to other modules. Whereas the command issued from the microphone can be interpreted alone, the other one coming from the VPD can only be interpreted in combination with a speech command. Hence, speech is the main communication mean used by the operator to dialogue with the system. For transformation of user’s voice into text strings, speech recognition software is needed.

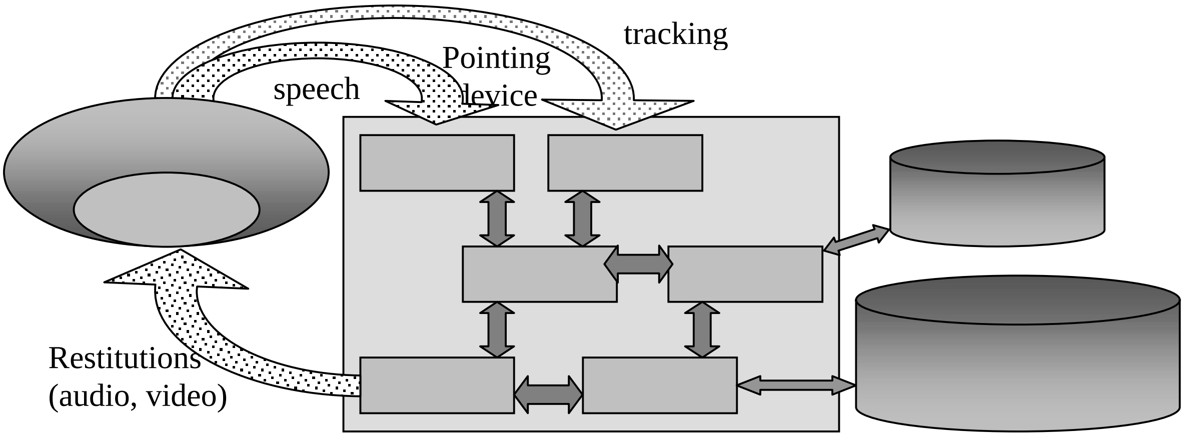

Figure 5: diagram of STARMATE system

3.3 Restitution Module (RM)

The RM manages the restitution provided to the user. Providing a command interface, it allows the other modules to activate and deactivate augmentation objects. Those objects can be 3D models, e.g. representations of real objects, 2D objects like text windows, video or a system menu and as acoustic objects sounds and spoken text. Furthermore the RM is in charge of the determining objects, pointed at with the VPD, by handling intersection and occlusion problems. Both real and virtual objects can be designated.

3.4 Perceptual Awareness Module (PAM)

This module provides the 3D tracking information, i.e. pose of user and the object to be worked at, forming the base for augmentations. Besides tracking calibration of the cameras, the user and the VPD are tasks of the PAM module. Calibration of the cameras is the precondition for good tracking results, calibration of the user means to determine intrinsic parameters like the distance between the eyes, in order to allow good visual restitutions and calibration of the VPD defines the orientation of the pointing ray.

3.5 Scenario Management Module (SMM)

The SMM manages scenario-specific data of the STARMATE application. It parses the items contained in special scenario files and creates the corresponding data structures, that can be processed by the system. Additionally it keeps track of the current scenario status and initiates the author-defined augmentations of the appropriate time in the scenario. Find more in section 4.

3.6 Information Retrieval Module (IRM)

This module is in charge of accessing the information stored and organized in the different data bases of the system. It defines the communication protocol for the RM and SMM for accessing the information stored in the STARMATE data structure created by the SMM.

4 Interface to the end-user

This section deals with the question: how can an end-user apply the system to a certain real case? The short answer is: by defining a so-called **Starmate Scenario file** (STS-file). All augmentations foreseen in STARMATE belong to a precise procedure encoded in an STS-file. The scenario progress management is split in two parts: First, the default procedure, consisting of steps executed sequentially. These steps perform actions corresponding to the different augmentations required by the default part of the scenario. Second the alternative information supply, consisting of additional augmentations that can be supplied at any stage of the default procedure progress on user's demand.

5 Partners And Demonstration Of Use

The STARMATE project consists of a multi-disciplinary consortium including engineers, computer scientists, instructional professionals, human factor experts, aircrafts, optronics and nuclear maintenance specialists. The consortium is built of six partners from different European countries: Thomson-CSF Optronique (TCO), Computer Graphics Center (ZGDV), Dune Ingegneria dei sistemi srl (DUNE), CS Systems d'Information (CSSI), Tecnatom (TECNATOM) and EADS AIRBUS SL (EADS).
During the project the system will be demonstrated, in real work scenarios, at three end-users sites. These end-users will control and validate the system's functionality, and particularly, the pertinence of the maintenance scenarios:
TCO will be the first end-user, using the system in the context of optronic products manufacturing and maintenance (those illustrated in figure 1). EADS. will use the system in the context of aeronautics construction for assembling wings of a famous European aircraft. TECNATOM will apply the system to maintenance on complex pumps and turbines used in nuclear power plants.

6 Experience and Conclusion

This paper presents the current state of the STARMATE project and addresses mainly system specification and design aspects. The project is now at the end of the specification and design process, which was done based on significant effort regarding the evaluation and risk assessment of different scenarios and configurations in order to prepare a real industrial system rather than a toy like demonstration.
The STARMATE project started in March 2000, and is foreseen to run for a duration of 36 months. Generally speaking it totalizes 280 man months of work for a team of 7 partners representing roughly 30 persons.
The project is constrained by several factors that will determine the marketability of the system. Among these constraints, the terminal cost of the equipment used to develop the

maintenance/training system is determining. This imposes the use of off-the-shelf hardware and software, when possible.

Another strong constraint is the ergonomy of the system. In addition, the choice of see-through vision, although it provides a more natural interface for such an application, makes the task difficult. In this regard, no product of the market really meets all our requirements and we had to make trade offs to adapt to existing HW.

Another extremly difficult task is to have a reliable, accurate, real-time 3D tracking system. In this domain, the consortium secures the developments by using a conventional electromagnetic system while developing a new optical approach for alleviating problems inherent to electromagnetic trackers.

Summarizing, STARMATE integrates innovative leading edge technology (i.e. Augmented Reality, multi-modal interaction and access to complex information) and standard technology available in the market where possible. The high complexity of the system and the aim to achieve a high level of user-friendliness are the main tasks that have to be managed by the profound specification and the application in real work situations.

The usage in three very different contexts during the project and the overall design, establish a basis in order to reach a high degree of generality allowing to widen the range of applications after the project. Overall, STARMATE intends to improve workers technical sharpness and therefore company competitiveness.

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