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Augmented Reality Platform for Collaborative E-Maintenance Systems

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1. Introduction

One of the recent design goals in Human-Computer Interaction is the extension of the sensory-motor capabilities of computer systems enabling a combination of the real and the virtual in order to assist the user in performing his task in a physical setting. Such systems are called Augmented Reality (short: AR). The growing interest of designers for this paradigm is due to the dual need of users to benefit from computers and interact with the real world.

AR is a new interactive approach, where virtual objects (such as texts, 2D images and 3D models) are added to real scenes in real time by using sensing and visualization technology. The computer generated digital information is overlaid on the user's physical environment so that he can perceive currently important information where needed.

Augmented Reality (AR) is derived from Virtual Reality (VR) in which the user is completely immersed in an artificial world. In VR systems, there is no way for the user to interact with objects in the real world. Using AR technology, users can thus interact with mixed virtual and real worlds in a natural way (Zhong & Boulanger, 2002).

AR research is of major interest in several domains. Azuma gives a description of various applications of AR systems in (Azuma, 1997) including medical visualisation, manufacturing and repair, robot path planning, entertainment and military aircraft.

AR application is an excellent domain for maintenance tasks in industrial environment (Changzhi et al, 2006). AR allows the user to see virtual objects increased upon real world scenes through display devices such as PCs, Laptops, Pc-Pockets, Video-projectors or Head Mounted Displays (HMD). The technician can interact with the virtual world and may dispose of additional information in various forms; for instance additional maintenance tasks instructions may be given in the form of texts, images, video or audio augmentations.

Several maintenance platforms based on AR have been developed. ARVIKA (Marsot et al., 2009) introduces AR in the life cycle of industrial products, AMRA implements a mobile AR system in an industrial setting (Didier & Roussel, 2005), STARMATE (Schwald et al., 2001) assists the operator during maintenance tasks on complex mechanical systems, ULTRA (Riess & Stricker, 2006) has developed a software architecture that enables production of

augmented reality manuals and on-site support of (mobile) maintenance workers. Also, A prototype of automobile maintenance (BMW) based on AR are presented in (Platonov et al., 2006) using see through system. More recently, the project ARMAR (Henderson et al., 2010) has been interested in exploring the extent to which AR can increase the productivity, the precision and safety of maintenance personnel.

These platforms provide many advantages for repair task improvement, but not sufficiently. In some cases, technicians cannot repair equipments even with AR means. This occurs when a new failure appears, in which case, the corresponding scenario does not exist in the database. The main solution is to contact remote experts (with required qualification level) to provide maintenance procedures through collaboration with the field technician.

In recent years, systems supporting remote collaborative work for industrial maintenance have appeared. But, increasing importance is given more to collaborative principles (Bangemann et al., 2006) rather than maintenance and AR aspects (Bottecchia et al., 2010).

In (Zhong & Boulanger, 2002) a prototype is presented in which operators equipped with display devices are supervised by an expert. This latter can only provide audio indications. Sakata and Kurata (Sakata et al., 2003), (Kurata et al., 2004) developed the Wearable Active Camera/Laser (WACL) which allows the remote instructor not only to independently look into the worker's task space, but also to point to real objects in the task space with the laser spot (Alem et al., 2011). In (Bottecchia et al., 2010) a maintenance collaborative system entitled CAMEKA is described, which enables the expert to give visual indications to an operator with an AR display device fitted with a camera. What the camera sees is sent to the expert who can "capture" an image from the video flow, add notes, then send back the enriched image to the operator's display device.

Existing AR systems are based on a single technician who repairs a single machine. Others are based on a local collaboration through available on-site experts. This situation does not guarantee direct task assistance. In some cases, the experts are not available while in others, the existing local experts lack sufficient competence. It, then, is necessary to call onto a remote expertise for the technician's performances improvement. Also, the capitalization of expert's know-how is guaranteed.

Our area of interest is the establishment of a distributed platform allowing collaboration between technicians and remote experts based on AR benefits. Two main aspects are studied and developed in our case. The first aspect addresses a new collaboration strategy based on Service Oriented Architecture (SOA) which offers efficient solutions in terms of information transfer and exchange, data heterogeneous management, etc. The second aspect ensures the virtual objects (maintenance procedures) transfer from the remote expert in real time. The result is a visual space shared by the technician and the remote expert.

The content of this chapter is organised as follows. In section 2, a collaborative platform supporting AR interaction is presented. Section 3 describes a global industrial maintenance scenario. Implementation and results are presented in section 4. Finally, in the last section, a conclusion and perspectives are given.

2. E-maintenance platform based on augmented reality concept

In this section, the collaborative platform supporting AR interaction is built. The expert should be able to insert augmentation into video stream to increase the operator's view in real time, so that he understands the tasks to be achieved.

To address this need, we have developed concepts concerning the data transfer (augmented 2D/3D objects) and the remote collaboration.

2.1 Tracking system and virtual objects transfer

Tracking is a very important research subject in the field of augmented reality (Fiala, 2004), (Comport et al., 2005), and the vision-based tracking method is usually appropriate. Tracking methods use cameras that capture real scene as sensing devices. So, to apply AR to maintenance support, the positions and orientations of users in real time must be measured with high accuracy. Among the tracking technologies proposed in previous studies (Comport et al., 2005), marker-based tracking, which uses image processing technique to measure the relative position and orientation between a camera and markers (transformation matrix marker/camera), seems to be appropriate to industrial maintenance context. In fact, the most popular tracking method, which uses square markers, is ARToolkit (Kato & Billinghurst, 1999).

ARToolkit (Augmented Reality Toolkit) is an open-source software library used to develop augmented reality applications. It was developed by "The Human Interface Technology Laboratory" (HIT Lab) at Washington University. It uses vision techniques to calculate position and orientation of the camera relative to markers. The programmer can use this information to draw the 3D object and to insert it correctly in the real scene.

ARToolkit guarantees the virtual object tracking when the camera (or user) changes position. The "ARToolkit" library has several types of markers (Kato & Billinghurst, 1999) (see Fig. 1).

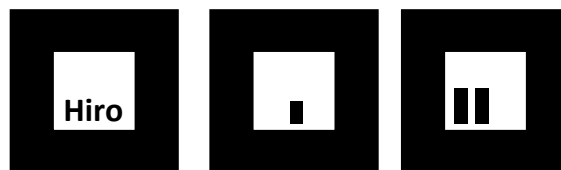


Fig. 1. Examples of ARToolkit's markers.

The markers are in a black square form with a code inside. This marker is a simple form that can easily be identified for the insertion of a virtual object. The position and orientation of the camera can be calculated by identifying the markers in a video stream.

However, like other vision-based tracking, the tracking with ARToolkit suffers from the lack of robustness. In this case, our team proposes (Bellarbi et al., 2010(b)) a new version of ARToolkit called i-ARToolkit (improved ARToolkit) that gives solutions to ARToolkit problems.

The first problem of ARToolkit is the use of static thresholding method that cannot adapt to changing environmental parameters (brightness level). i-ARToolkit applies dynamic thresholding approach to guarantee markers recognition even if environmental properties change.

The second problem concerns the virtual objects instability in the real scene. This is due to the uncertainty of the transformation matrix. i-ARToolkit proposes an approach which takes into account this uncertainty.

In summary, i-ARToolkit tracking system performs the following steps (Bellarbi et al., 2010(b)):

Step1: Open a video stream

Step2: For each captured image:

- 2.1 Calculate the optimal threshold value from the captured image using Otsu method (Otsu, 1979).
- 2.2 Transform the captured image to a binary image using the calculated threshold value.
- 2.3 Detect black squares markers in the binary image.
- 2.4 Calculate the camera's position and orientation (calculate the transformation matrix).
- 2.5 Apply the stabilization algorithm (Bellarbi et al., 2010(a)).
- 2.6 Superimpose the virtual objects upon the captured image (using the calculated transformation matrix).

Another problem usually appears when applying AR in maintenance; it is the non-detection of markers when the technician works in a large space. This occurs when the camera is far from the marker. Fig. 2 shows an estimation of the maximum detection distance of i-ARToolkit markers.

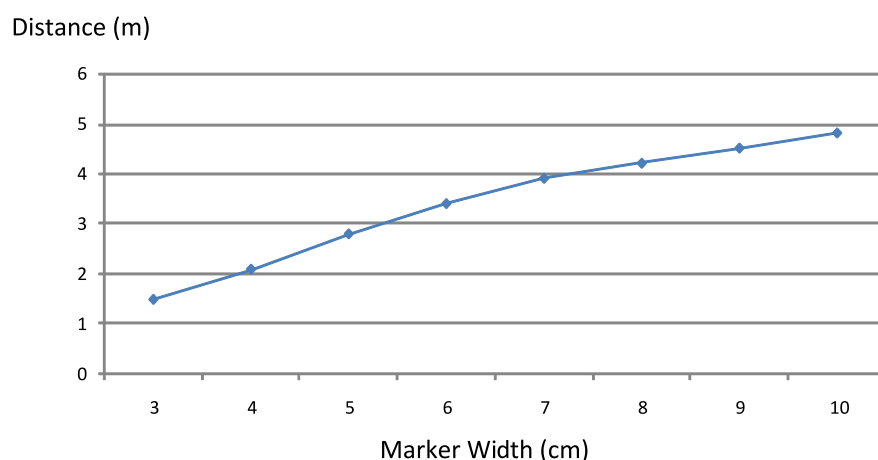


Fig. 2. Detection distance vs marker width

The proposed solution, inspired from (Hirotake et al., 2010), is to establish a relationship between a number of detected markers in the captured image and the distance between the camera and the markers.

Fig. 3.a shows that the detected markers become very numerous and the size of each marker on the image becomes very small when the distance between the camera and the markers is long. It therefore becomes difficult to calculate the transformation matrix for each marker. The markers size on the image is too small. In this case, a global transformation matrix is calculated to encompass the transformation matrices of the detected markers. This principle enhances the stability of inserted object.

On the other hand, as shown in Fig. 3.b, when the distance between the camera and the markers is short, the number of the detected markers becomes small and the markers sizes on the image become very large. In this case, it becomes possible to obtain more stable transformation matrix since the marker size on the captured image is sufficiently large.

Once the transformation matrix between the marker and the camera is calculated, augmented objects which represent maintenance procedures are easily inserted.

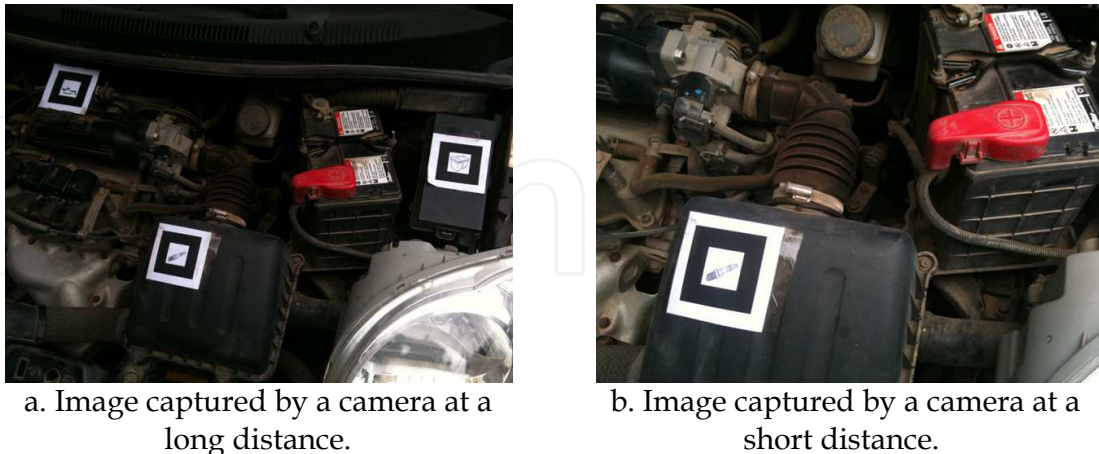


Fig. 3. Example of car engine with markers

The configuration given in Fig.3 allows the technician to view maintenance scenarios even if he changes position. A number of markers attached to preregistered locations in the area of a repair could serve as anchor points for labels, instructions, and other virtual content. In most cases, maintenance units could install these markers permanently without interfering with system components. For cases when this was not possible, technician could affix temporary markers to predetermined mount points prior to a repair sequence.

In most cases, the technician has difficulties to place the markers in adequate and precise position. For that, it is recommended to choose particular preregistered locations (example: corners) to perform easily markers placement.

To resolve the placement's marker problem, the best solution is to replace printed markers with natural features (such as visually unique parts of an engine), making possible markerless tracking (Bleser et al., 2005), (Comport et al., 2005). In our future work we plan to develop a markerless based method for maintenance field.

2.1.1 Virtual objects transfer

When a technician performs a difficult task, he can be assisted by a remote expert. The difficulty lays in how to send the augmented scene from remote the expert to the technician's visual scene. For this reason, two approaches are proposed. The first one consists in computing the technician's position (transformation matrix marker/camera) from the captured images. The captured images and the transformation matrix are both transmitted to the remote expert (see Fig. 4).

As observed in the above figure (Fig. 5), the technician just sends the captured images. The expert should have a tracking system to detect the makers and to calculate the transformation matrix. The remote expert's tracking system takes an additional time to perform the different operations. In addition, to calculate the transformation matrix, the images must be sent to the remote expert without being compressed. The markers detection in the compressed images gives poor results.

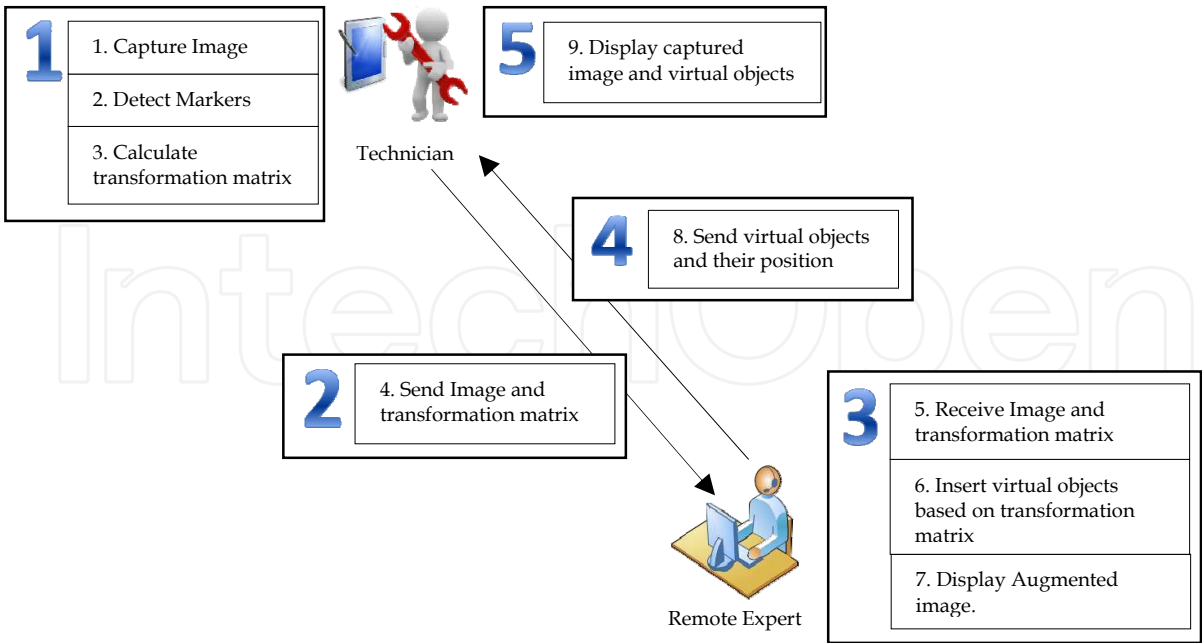


Fig. 4. Essential steps of the first method.

The second approach consists in sending the captured images alone, from the technician to the remote expert. Besides the technician, the transformation matrix is also computed at the remote expert, (see Fig. 5).

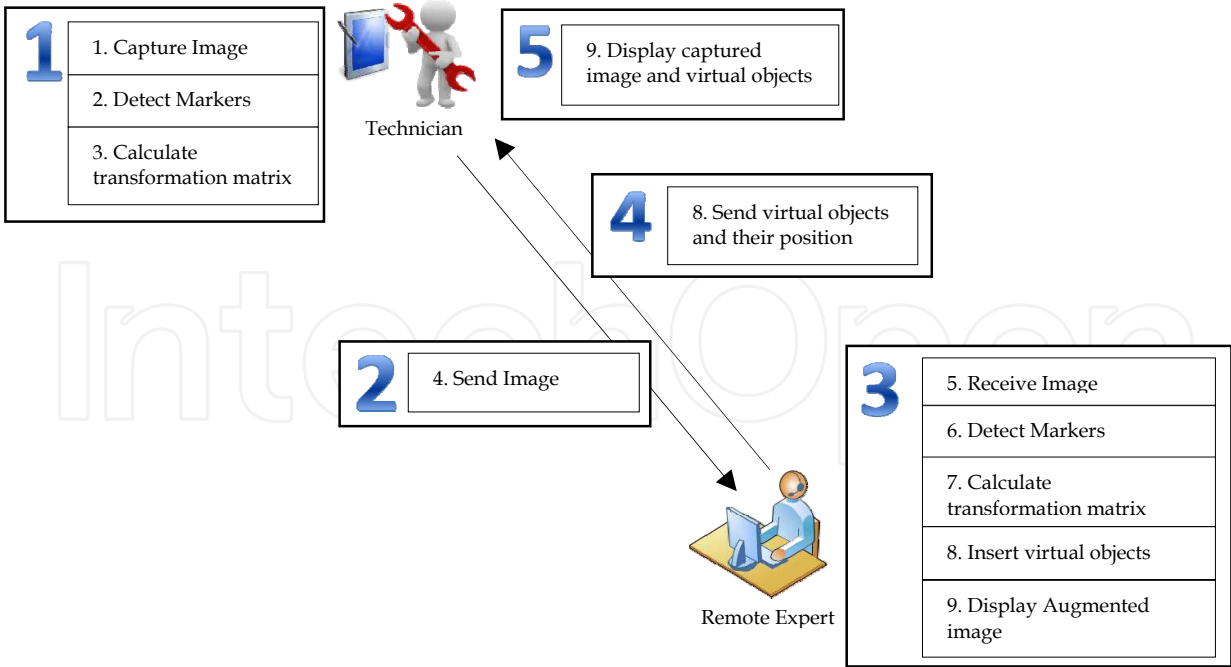


Fig. 5. Essential steps of the second method.

The first method gives better results since the markers detection is performed at the technician’s device. The transformation matrix and the images are transferred to the remote

expert’s computer. With this approach the expert does not need a tracking system to calculate the required parameters. Also, the images can be sent to the remote expert in compressed form. So, the computing time is reduced.

According to this comparison, the first method is adopted to guarantee the best data exchange between the actors. The next section gives more details about the data exchange principle in a collaborative context.

2.2 Remote collaboration

In this section, our aim is to develop approaches for remote collaboration based essentially on the Web Services concept. In this case, we are interested in developing a communication module (for chat, file, image and augmented video transfer) to take into account the heterogeneity problem between different hardware (Pc-Pocket and PC-Tablet) and software platforms (operating systems, programming languages...). The use of Web Services ensures the interoperability between the applications of different actors.

2.2.1 Distributed and mobile e-maintenance platform

When the technician lacks competence to repair broken down equipment he contacts a remote expert to obtain appropriate solutions. A distributed platform is then required to facilitate this collaboration.

A distributed system is a set of interconnected devices which collaborate to perform a set of tasks. The tasks are called by a remote services exposed in a web server. Based on Web Services, this system can manage heterogeneous applications geographically dispersed.

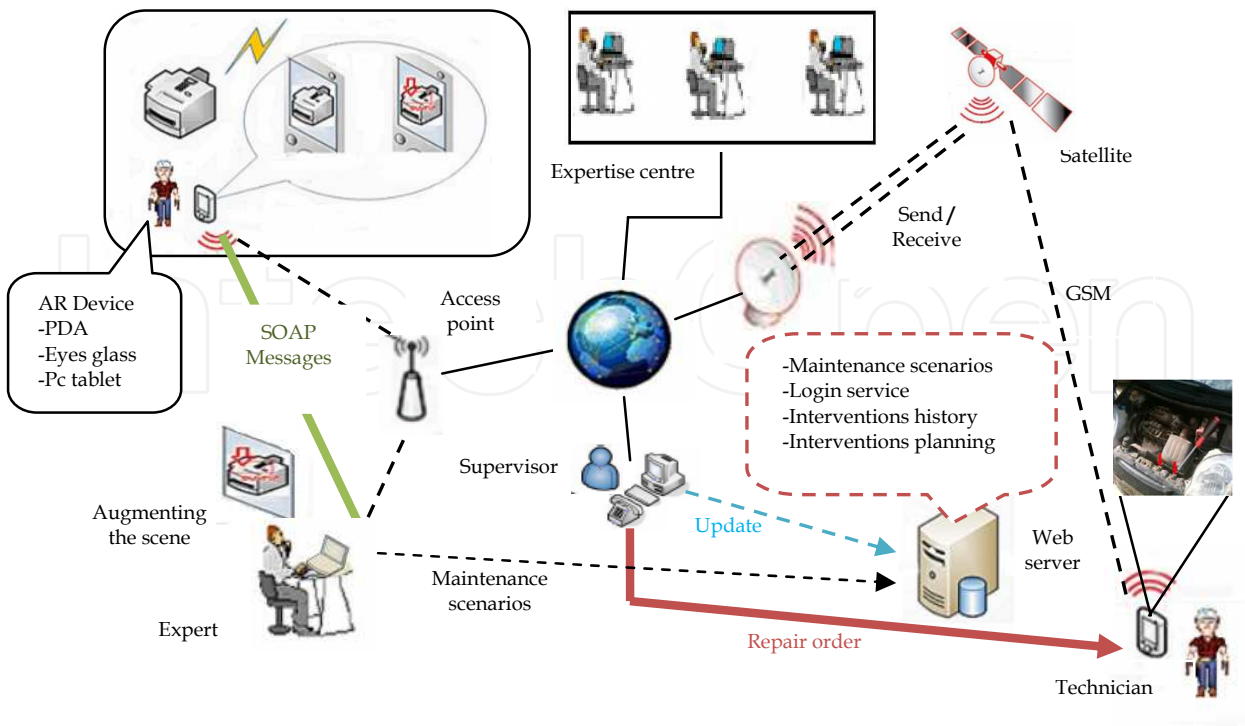


Fig. 6. ARIMA platform configuration.

In order to build infrastructure for data exchange via services, we adopt “SOA” (Service Oriented Architecture) concept which is a paradigm that allows organizing and exploiting distributed capabilities that may be under the control of different ownership domains (Nickul, 2007). Based on this architecture, we have developed our platform named ARIMA (Augmented Reality and Image processing in Maintenance Application).

Fig.6 shows a distributed and mobile platform allowing a dialogue between technicians using mobile devices (such as PDA, Pc-tablet, eye glass...) and remote experts.

2.2.2 Web services for e-maintenance

The interaction between actors (experts and technicians) requires communication platforms. Despite the advantages of the existing technologies, it cannot effectively manage the heterogeneous running environment especially when using various communication tools such as Pc-Pocket, Pc-Tablet, HMD and others. The Web Service presents efficient solution to resolve this problem. The main role is to facilitate data transfer between actors using the Internet network.

A Web Service is a software module which performs a set of discrete tasks. It is a set of services which can be invoked through a network, especially the World Wide Web, accessible via standard Internet protocols (Booth et al., 2004). A Web Service has an interface described in a WSDL (Web Service Description Language) format which exposes the method to be invoked by a web server (binding, port, services). Other systems interact with the Web Service by sending SOAP (Simple Object Access Protocol) messages to the web methods. These messages use HTTP with an XML serialization in conjunction with other Web-related standards. In other words, a Web Service is a set of related application methods that can be remotely accessed through a network (such as a corporate Intranet or Internet itself). WSDL documents are indexed in searchable Universal Description Discovery and Integration (UDDI) Business Registries, so that developers and applications can locate the Web Services.

Web Services are both characterized by the reuse facilitation. They are independent from used platforms (Windows, UNIX...) and programming languages (C #, JAVA, VB...). This interoperability form makes Web Services one of the most used technologies to design distributed applications (Leymann, 2003). In our case, Web Services principle is adopted to establish a distributed mobile maintenance platform.

As a most important concept of Web Services, we are interested to use WCF (Windows Communication Foundation). It is a new feature of Dot NET Framework version. It supports the sending of HTTP data. HTTP protocol facilitates the communication in the Internet network (Scott, 2007).

The actors consume Web Services by sending SOAP file. The services are described in a WSDL file and distributed through a UDDI registry. This allows easy collaboration between actors to resolve several technicians' task. The actors communicate by exchanging SOAP files through a service provider in order to run web methods. These web methods are described in WSDL file which is hosted in the service broker. Fig. 7 shows an example of a Web Service requested by two experts and one technician in a collaboration context.

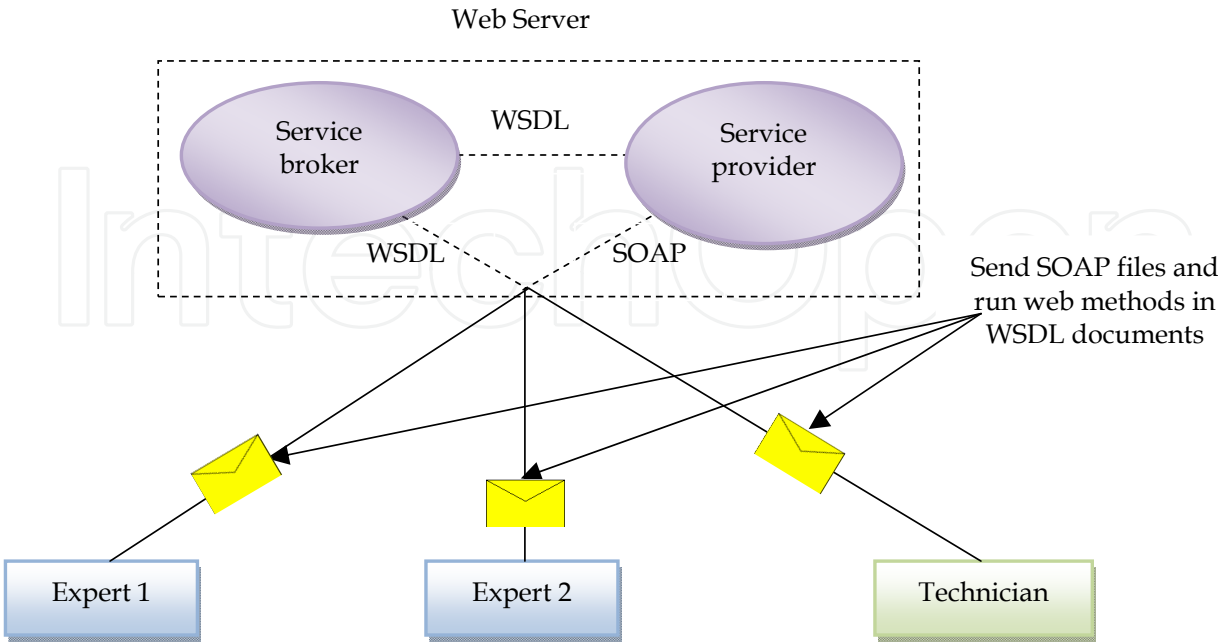


Fig. 7. Collaboration principle between actors.

2.3 Internal operation of ARIMA platform

Initially, the technician receives an alarm about failed equipment. He proceeds to a first analysis and tries to formulate a diagnosis. When he is unable to repair, he contacts a remote expert using internet network. The essential aspect is to guarantee the reliable data exchange using SOAP file through an access point in Internet network.

The data transfer process is described as follows (see Fig 8): the technician captures a video of failure's location. For every captured frame, a tracking system detects the markers and calculates a transformation matrix. Both captured video and transformation matrix are transmitted to the remote expert. The expert adds virtual objects (scenarios) according to the scene. The inserted virtual objects and their positions are sent to the technician. The virtual objects are received and displayed according to their positions affected by the remote expert.

The data transfer is based on a client/server architecture. Each user must authenticate to the system. For that, the user runs a login method "login (username, password)". The data is encapsulated in a SOAP messages. The server checks the username and the password in the database and sends the answer to the user. For video transfer, the technician runs the web method "send(image, transformation matrix)" to send the captured frame and the calculated transformation matrix to the web server. The expert performs the web method "receive(image, markers)" to retrieve the captured frame and the transformation matrix. Then, he adds augmentations. The expert returns the result to the technician by running the method "sendObject(objectPostion, Object)". The technician runs the web method receiveObject "(objectPostion, Object)" to receive and displays the virtual objects (see Fig. 8).

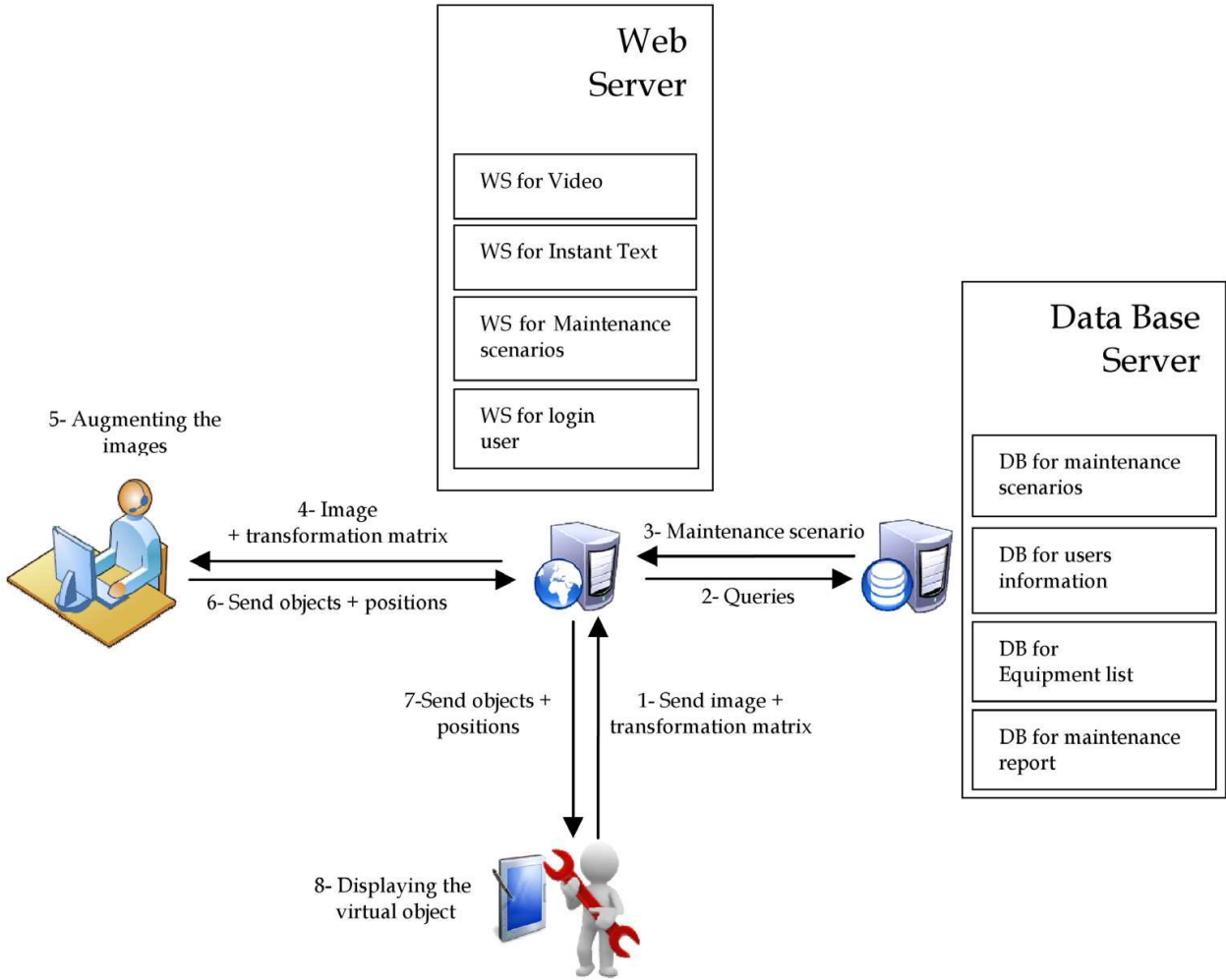


Fig. 8. Collaboration between expert and technician.

3. Global industrial scenario

ARIMA platform operation is based on a set of scenarios which are given as follows:

First, the supervisor (or team leader) sends the repair order to the technician who checks his schedule.

When the failure is identified, a maintenance scenario is then displayed in "augmented" form (see table 1) through the technician's output device.

As for the technician, due to the lack of competence, he collaborates with a remote expert. The server establishes a link between the expert and the technician. A dialogue is then performed between the two actors in order to identify the failure. To obtain more information, the expert can request documentation and/or the previous maintenance reports. Once the failure is analysed, the expert sends the augmented maintenance procedure to the technician's display device.

When the intervention is achieved, the technician fills out a maintenance report which contains all the information pertaining to the failure and the intervention procedure. This report is transmitted to the supervisor (for validation) and then stored in the interventions history database.

Augmentation	Function
Texts	Indicates the components name or the maintenance scenarios
Pointing arrows	Indicates the components or how to execute the maintenance scenario
Tools	Shows the tool type to perform the operation
Sound	Guides the technician through voice indications

Table 1. Types of augmentations.

4. Implementation and results

In this section, a maintenance application using ARIMA platform is implemented. Our tests are performed on a car engine (see Fig. 9).



Fig. 9. Example of equipment (car engine).

The technician observes that the engine has failed, but he cannot identify the problem. So, he contacts a remote expert in order to perform a detailed diagnosis. The two actors collaborate by exchanging data: chat, files, images and videos.

In our case, two failure types are treated. So, two maintenance scenarios are proposed. For the first failure, the collaboration is essentially based on a video exchange data. This requires the use of i-Artoolkit tracking system. For the second failure, we use images for exchange data (no video transfer). In this case, the tracking system is not necessary.

First case study: the engine makes much noise

The technician uses his Pc-Tablet, captures the video scene and sends it to the expert. He indicates, by chat, that the engine makes much noise. The expert views the video scene and proposes a maintenance procedure (check the oil level). The expert uses the augmentation editor to insert corresponding 3D augmentations (text and arrows) in the viewed scene. The augmented video is then transmitted to the technician (see Fig. 10). The collaboration continues until the engine is repaired.

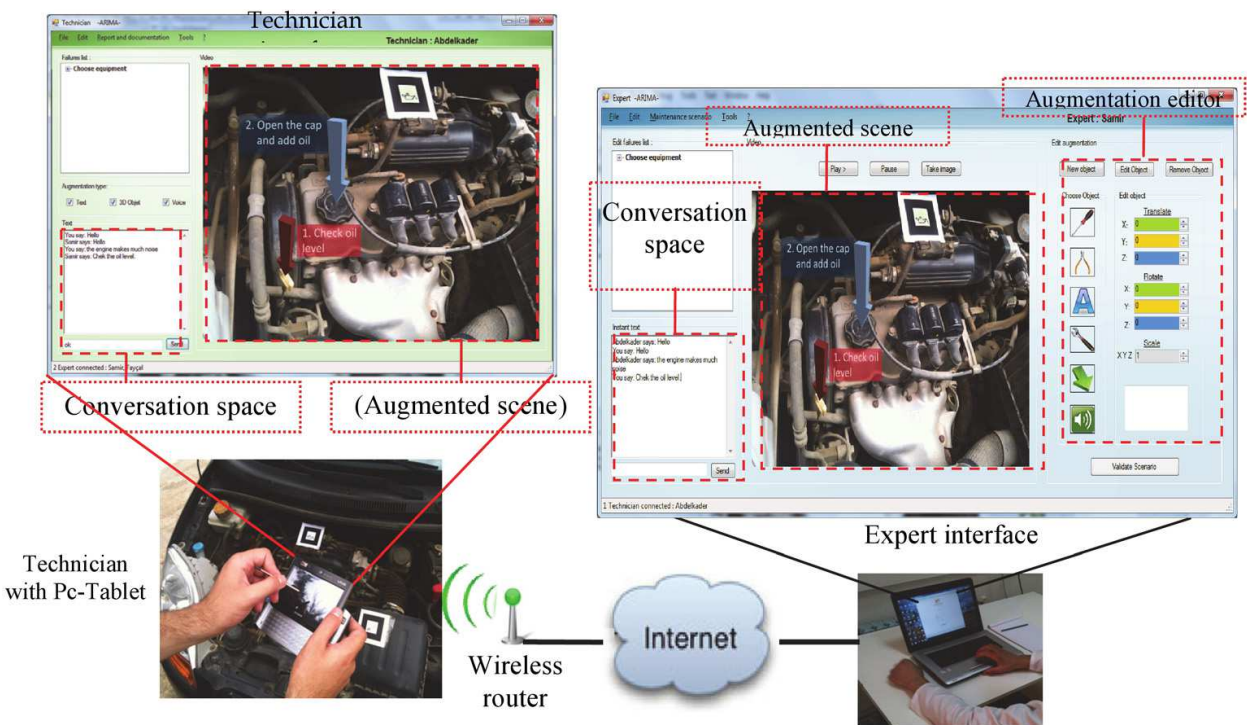


Fig. 10. Example of maintenance collaboration (first case study).

Second case study: the engine overheats

Using a Pc-Pocket, the technician captures an image (photo) of the scene (failure's location), and sends it to the expert. The failure concerns the engine temperature. Besides the chat, the expert uses a simple editor to insert 2D augmentations (screwdriver and arrows) that show the maintenance procedure (check the radiator) (see Fig. 11). The enhanced image is transmitted to the technician's Pc-Pocket.

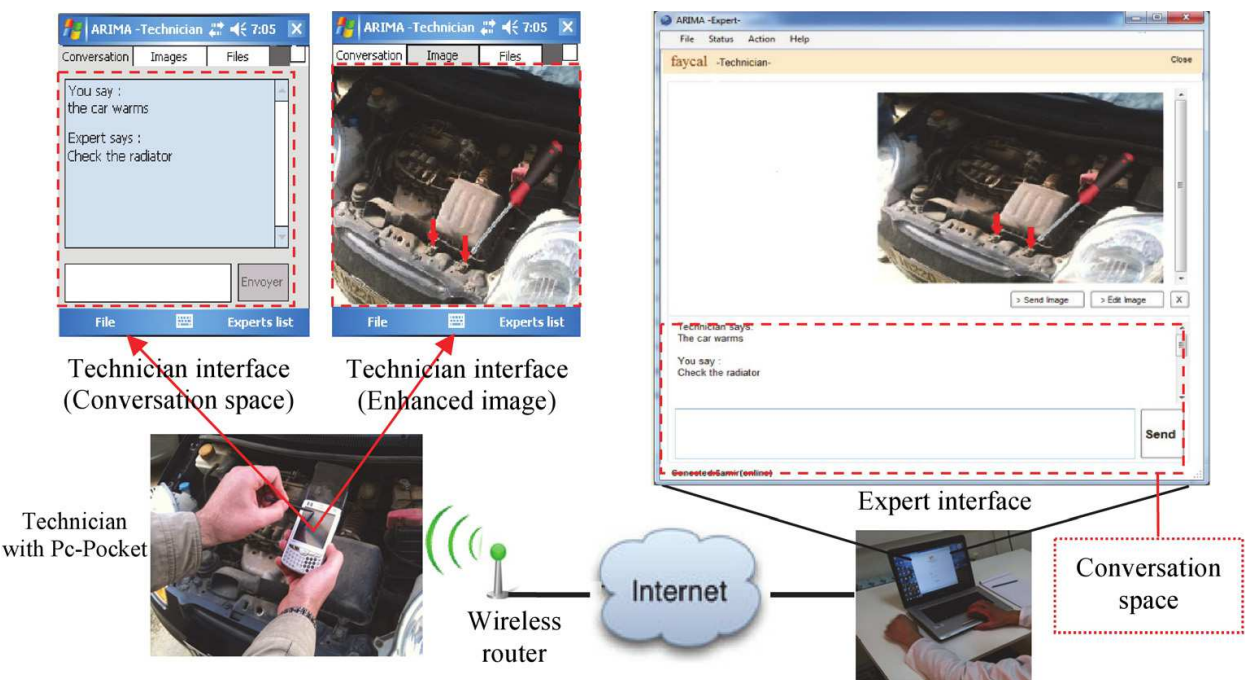


Fig. 11. Example of maintenance collaboration (second case study).

For hardware environment, technicians use a Pc-Pocket (HP, Windows mobile 5 with a video camera and internet connection) or a Pc-Tablet (Sony VAIO UX 280P, Windows XP, video camera and internet connection). Remote experts use a Laptop (Dell, Windows XP, Wi-Fi and camera). The collaboration is performed through access points which support wireless 802.11.

5. Conclusion

An AR e-maintenance platform design is presented in this paper. The aim is to help a technician during his intervention. As a result, we are focused on synchronous and remote collaboration between technicians and experts to complete maintenance and repair tasks by giving augmented information on the user's field of view.

Two principal concepts are treated and developed: remote collaboration based on Web Services and virtual objects transfer. The adopted strategy allows the technician to collaborate easily with a remote expert. Also, he can receive the augmented 3D scene in real time even if he moves.

This platform is applied in the case of a car engine repair. The maintenance operation is performed by a technician who collaborates with a distant expert to obtain maintenance scenarios displayed on the user's viewed scene. The results show the benefits of remote collaboration and AR for maintenance assistance (security, flexibility, saving time ...).

For future work, we aim to improve the proposed prototype in various ways. The user and interaction method need enhancement to make visualisation and manipulation of graphical objects easier. Also, the user's equipment weight can be reduced by using HMD. Moreover, sensors network installation is necessary to provide the equipment's state.

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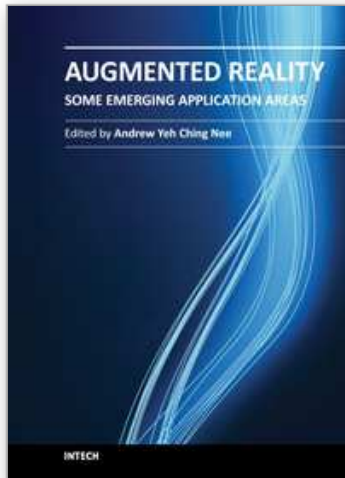
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Augmented Reality (AR) is a natural development from virtual reality (VR), which was developed several decades earlier. AR complements VR in many ways. Due to the advantages of the user being able to see both the real and virtual objects simultaneously, AR is far more intuitive, but it's not completely detached from human factors and other restrictions. AR doesn't consume as much time and effort in the applications because it's not required to construct the entire virtual scene and the environment. In this book, several new and emerging application areas of AR are presented and divided into three sections. The first section contains applications in outdoor and mobile AR, such as construction, restoration, security and surveillance. The second section deals with AR in medical, biological, and human bodies. The third and final section contains a number of new and useful applications in daily living and learning.

How to reference

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