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(Article begins on next page)

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Abstract: Augmented Reality (AR) is an emerging technology that can provide support to the provision of maintenance and technical assistance services by dispersed technicians, who are not convenient skilled to deal with the increasing complexity of modern products. This paper, through a case study in an industrial context, presents the main technical and organizational challenges that have to be faced in order to introduce AR in the delivery process of maintenance services.

Keywords: Maintenance Services, Augmented Reality technology, Technology introduction; Industrial application.

1. INTRODUCTION

This paper discusses the challenges in introducing AR systems in the delivery of maintenance and technical assistance services on installed products. These services include both the activities to ensure timely and efficient set up and recovery of the product operable/desired status, altered as a consequence of predicted faults, deteriorations, etc., and those that ensure the product availability. Examples of the first are installation, fix & repair, preventive maintenance, upgrade and of the second are diagnosis, inspection, telecontrol, etc. The provision of this kind of services is proven to be critical (Schmenner, 2009; Meier et al., 2010; Grönroos, 2008) for manufacturing companies that are working to increase the value offered to their customers integrating the selling of their product with product-related services (Mathieu, 2001 a, b). To achieve customer satisfaction, comply with contractual agreements and be profitable, these services have to be provided timely, effectively and efficiently. However, the following issues have to be faced:

1) *Product complexity.* Modern products present an increasing complexity, both to meet the evolving customer's needs and due to the integration of embedded computing systems (Meyer et al., 2009). Therefore, higher and higher skills are required to technicians since they must be able to maintain not only the electrical and mechanical parts but also the digital components of a machine and so, for example, to solve problems of software programs as well as to update and upgrade them. Moreover, with the rapid technological advancements and shorter and shorter time to market, the product innovation cycles get more frequent and so technicians continuously must keep their skills updated. However, to provide multi-skilled technicians that can accomplish any demanded service task can be highly inconvenient.

2) *Worldwide installed base.* With globalization and the increasing life-cycle of a product, organizations have to guarantee efficient services to installed bases of products that spread all around the world. For this reason technicians are dislocated worldwide too, becoming, according to Corso et al., (2006) dispersed workers. For an organization, the management (accumulation, distribution, etc.) of the body of knowledge that derives from the experience of dispersed workers is very cumbersome as well as to provide technicians with the information needed to perform any maintenance tasks.

In this context ICTs have been increasingly adopted for both communication and information management. For instance, it is very common that technicians are equipped with a PC that stores technical documentation and procedures and a mobile phone to ask their colleagues or supervisor for support when necessary. Both these devices have some limitations such as i) non intuitive information retrieval, ii) mobile devices do not support hands-free tasks, iii) misunderstandings may occur during a voice communication with a colleague, etc.

Augmented Reality (AR) is an emerging technology (Fenn and LeHong, 2011) that may help in overcoming the above mentioned limitations. Basically, an AR system supplements /augments the real world vision with real-time, interactive, computer-generated objects that coexist in the same space as the real world (Azuma et al., 2001). For these characteristics AR enables symmetrical communication between two parties and the right information in the right place can be displayed thanks to the superimposition of them on the real scene.

Up to now, the literature about AR identifies maintenance service as one of the growing application areas (Nee et al., 2012; van Krevelen and Poelman, 2010) but, as AR is still in its pioneering age, the literature contributions do not analyse in depth impact of its potential applications in real industrial contexts. In order to fill this gap and to understand the issues that limit the introduction of these systems, a case study with a company (hereinafter Alpha) that provide maintenance services to its installed base has been conducted.

The remainder of the paper is organized as follows: in section 2 the main AR systems that can be used in supporting field intervention are identified; then in section 3 the company and the experience conducted is described and in section 4 the main technical and organizational issues identified are discussed. The paper then concludes with some directions for further research (section 5).

2. AR SYSTEMS IN MAINTENANCE

When a technician needs to keep her/his focus on a specific zone while getting clear information such as the work sequence and the identity of some components to be served, Augmented Reality becomes a possible solution. In fact, AR can support maintenance service displaying in real time lengthy textual data, symbols, graphics, etc. superimposed to the real images (Henderson and Feiner, 2007).

A typical AR system includes: i) a computer system to run the AR application; ii) a digital camera to capture the real scene; iii) a tracking system to track the position and movements of users and objects and to link the virtual augmentation with a specific position in the scene; iv) a display to see the real scene augmented such as Head Mounted Display (HMD), handhelds (e.g. tablet, smartphones, etc.) or Spatial AR through projectors; v) a data acquisition system as gloves, tablets, PDAs to interact with AR application. Further details can be found in Zhou et al. (2008) and van Krevelen and Poelman (2010).

According to Porcelli et al. (2013), AR systems that can be used to support maintenance interventions can be divided in online mode and mobile collaborative (MCAR) systems. In online mode systems, all the useful information need to be uploaded in advance and converted into virtual models. In this way the AR system is able to guide a technician step by step in performing a task without the support of any other user. Thanks to tracking systems, it is possible to recognize the scene and the user movements and according to this, to display the augmentation in the right position. Examples of such AR systems can be found in Platonov et al., (2006); Henderson and Feiner, (2007); De Crescenzio et al. (2011).

A MCAR system, instead, allows several people to share an AR experience using their mobile devices (Billinghurst and Thomas, 2011). In particular it could be used to support complex interventions and when a troubleshooting activity is needed. In this case, two users are involved: a technician on-field and an expert, such as a product specialist, remotely located. Then, MCAR allows field users to send in real time the images they are seeing to the expert so that he/she can drive them in carrying out, step-by-step, the field task, giving aids through voice, gestures, and adding virtual objects. Examples of MCAR systems can be found in Bottecchia et al. (2010); Alem et al. (2011); Azpiazu et al. (2011).

The experiences described in those papers have two weaknesses: on one hand they usually are focused on technical and user-related issues such as tracking accuracy, latency in displaying the augmentation, ergonomics, user's stress, etc. and do not take into account the impact of AR introduction at organization level; on the other hand, the experiments often are conducted within the labs without the involvement of end users. To fill this gap, to have a practical demonstration of the use of this technology and to evaluate on the field the related impacts, a case study has been carried out.

In the next section the company selected as the case study is presented as well as the AR system and the settings used for the demonstration.

3. CASE STUDY

3.1 Company Description

Alpha is the Italian subsidiary of a leading multinational company that provides machines and equipment for the professional printing. In Italy it operates its own direct sales and service organisations and counts more than 30 service centres at customers' premise distributed all around the country. The reasons for the selection of Alpha are twofold: The 30% of its total revenue in 2010 comes from the after-sales service activities (38% are the selling of products) highlighting the importance of such activities within Alpha's portfolio. In addition, the products manufactured by Alpha range from simple MFPs (multi-function printers) for offices, through wide format printing systems for technical documents up to the most complex production printers (PP). According to this, as told us by the Alpha's national service manager

"we have to deal with different criticality and complexity levels of the technical intervention and so we design our service network with different levels of competence in order to adequately support the technical workforce. The introduction of ICT that could improve the service delivery system is thus an interesting opportunity".

The product selected for the demonstration is the newest model of continuous feed production printer (PP). It is the most complex and valuable product and it addresses a wide range of applications like transaction, TransPromo, and Direct Mail in a B2B context. These printers have high flexibility and the productivity can reach more than 1000 A4 duplex per minute. Besides mechanical and electrical parts, these machines are equipped with sophisticated controllers and software to manage the printing workflow. These products are sold in the B2B market and represent for the customer the core machines for their business, so that high levels of reliability and availability are requested. Usually the sale of the printer is bound to the signature of a service contract (that includes replacement of defective parts, help-desk service, firmware upgrade, installation, preventive maintenance etc.) where stringent service level agreements (SLAs) such as short response time, recovery time and high availability are defined. Therefore to satisfy its customers and to save money (i.e. penalties have to be paid for non-compliance with SLAs) Alpha needs to provide effective intervention in the shortest time.

To deliver field services on this kind of printers Alpha has a team of around 30 high skilled technicians in Italy. However, when some unexpected events occur or when a new version of printers reaches the market, support to perform the field intervention may be needed. To this concern, technicians are equipped with a PC that can be used for two purposes: i) to connect to the printer in order to perform some diagnostic task or to retrieve some information about its history and ii) to read not-interactive manuals and procedures. In addition, if a technician cannot solve the problem by himself (1st level of intervention) Alpha provides other three levels of intervention with technicians/product specialists with an increasing level of technical skills. The first attempt is then to call the upper level and ask for suggestions using a mobile phone; if the problem cannot be solved the product specialist tries to connect remotely to the printers and if even in this way it is not possible to identify the failure's cause, he/she directly visits the customer.

3.2 Description of AR Technology selected

The facing of an unexpected event has been pointed out as the most critical situation for technicians. In addition several issues regarding the communication among product specialist and field workforce has been highlighted, such as the hardness in collaborating for solving the faced problems using traditional devices (e.g. mobile phone). For these reasons, a MCAR system was chosen as a possible solution.

In particular, the selected system enables the collaboration among the field technician and the product specialist: the first one wears a mini PC and a portable camera tied at the waist, and a near eye display, with the main camera and headset fixed on a helmet. The product specialist, instead, is remotely connected with a desktop computer where the AR software runs (see Fig. 1). He/she receives the stream video coming from one of the two cameras and can communicate with the technician giving audio and visual instruction (such as text, arrows, circles, 3D etc.). These aids can be helpful during troubleshooting activities, in order to understand the cause of failures as well as to guide clearly the technicians in performing the machine recovery. The tracking system is markerless so the AR software uses a natural feature recognition algorithm to determine the technician's position in the scene and so to superimpose the virtual information in a specific point that does not change even if the technician moves him/herself. To connect the two users both Wi-Fi, cellular (such as UMTS) and a satellite network can be used. This MCAR system has been designed to minimize the bandwidth required for the connection and the transfer of audio and video data (384 kb/sec). For the demonstration a Wi-Fi network was chosen.

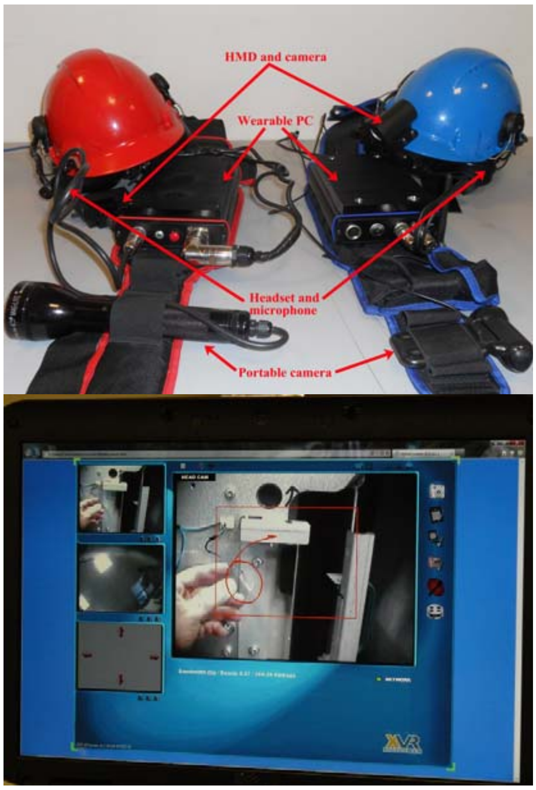

Fig. 1 MCAR system.

3.3 Demonstration settings

The practical demonstration in a real context of the selected MCAR system was organized. During this demonstration, both technicians and product specialist could use the system so they became aware of its usability with respect to the aims of their work. Information was then collected through interviews and short surveys administered to the people involved. Their position in Alpha and the role in the case study are described in Table 1.

Before proceeding with the demonstration, its settings were carefully defined. A company (Beta) using the production printers manufactured by Alpha, that was available to participate to this experimentation was selected. Since Beta works in the TransPromo market, where high volumes of documents must be printed and shipped to customers with very limited times (i.e., at the end of the quarters when bank statement are closed and sent to the bank account holders) printers' availability is a must-have and, therefore, this performance is delivered by Alpha according to contractual SLAs.

Table 1. People involved in the case study.

Name	Position	Role in the case study
Informant A	National service manager	Coordinator of activities and people involved; management of customer relations
Informant B	Product (PP) specialist	Expert that guides the technicians in executing the intervention
Informant C and D	Technicians skilled in PP	Field technicians that need support in executing the intervention

For this reason, Beta acknowledged the value of AR system and upon request confirmed its interest and availability to take part in the case study. Then, in order to evaluate the learnability and ease of use of the system one (and only one) of the technicians (Informant C) were trained the day before, in a two-hour session. In particular, Informant C was instructed on how to wear the equipment, to visualize and to use the virtual content superimposed to the real environment. Finally, a maintenance scenario that was considered suitable for the aim of our study was identified. This consisted in: firstly a troubleshooting activity in which the cause of a fault must be discovered, then the determination of the component (i.e., a disconnected switch) that caused the fault, and lastly the remedy to be implemented according to a given procedure. The depicted scenario, during the demonstration, was repeated by Informant C and D in different times, while being both supported by Informant B, that was located in a room next to the printer and not in a real remote location.

At the end of the demonstration both the actors (Informant B, C and D) and Informant A were interviewed in order to get their impressions. Interviews were face-to-face, tape-recorded, then transcribed and sent to the Informants for validation. Informant C and D answered also a short survey about their perception of usefulness and ease of use of the MCAR system.

4. RESULTS DISCUSSION

The overall evaluation of the MCAR system was very positive.

"When there is a strong need for collaboration, as for new products, MCAR is certainly useful"

stated Informant C recognizing the usefulness of the system. In particular, this was highlighted in situation when a certain extent of uncertainty must be faced by the technicians since the product served and/or the maintenance tasks are not well-known.

"I cannot deny my enthusiasm for the system that, if properly implemented can give good results, greatly improving also my daily activities"

stated Informant B. In particular high level of effectiveness and efficiency in the bidirectional communication has been recognized. The possibility to exchange visual information in both directions was proven to simplify the communication and avoid several misunderstandings. In addition, using MCAR, the number of visits at customer's premise for the specialist could be greatly reduced. Finally, the tested device has been appointed by Informant B, C and D as

"easy to use, simple and user-friendly".

On the other hand, interviews also highlighted some criticalities, pertaining to both technical and organizational issues that have to be overcome in order to make MCAR systems a real option for companies. In the following the mentioned problems are further discussed.

4.1 Technical issues

The technical issues are related to: devices; data transfer; content generation.

4.1.1 Devices

Both wearable and handheld devices are perceived by end users to have some limits with respect to allowing the execution of the work activities. In fact, both HMDs and handheld devices, irrespective of they allow or not hands-free operations, present problems related to size, weight and stress, especially in case of a prolonged use. Therefore, when choosing the I/O devices it is necessary to take into account the context requirements. For instance, the usage of a helmet as a support for the camera, display and headset is feasible only in case, for safety reasons, workers are obliged to wear it. In addition, the cable connection between the display and the mini PC limits the technician's mobility and should be replaced with a wireless data communication system. Then equipment such as portable camera was perceived extremely useful during the demonstration, as it has been proven to provide access to tight areas. Nevertheless, the addition of LEDs to illuminate the tight area and the possibility of adding virtual objects by the expert also on this video stream were appointed as possible improvements. Finally, problems related to the prolonged use of AR system including the battery life and other ergonomics aspects have been identified even if not addressed in detail.

4.1.2 Data transfer

In general, both online mode and remote collaborative AR systems have to deal with the transfer of complex data (such as images, video, 3D content with huge data loads). To this concern, especially online mode technology may not have the required computing power to run the software application. Even if this issue will be for sure overcome in the next future with the development, for instance, of mobile devices with more powerful embedded microprocessors, this is still a strong limitation for the adoption of these systems especially in contexts such as the one investigated. Conversely, since a secure communication between remote users and the transfer of complex data is the core of MCAR systems, this will be always a central issue irrespective of the advance of the computing power of embedded microprocessors. Concerning the adopted telecommunication infrastructure, possible solutions are cellular, wireless, or satellite network. Irrespective of the infrastructure, in case security issues have to be considered, specific protocols need to be carefully implemented to ensure secure data transfer across the network. In particular, this was remarked by Informant B as the

"problem to connect the machine with the external world"

since customers are not confident in allowing external access to their intranet and databases. Therefore, besides improving transfer rates, the development of protocols for securing data transfer might represent a first step towards the introduction of AR system.

4.1.3 Content generation

With respect to content generation, two issues arose. The first concerns the possibility to collect data, information and documents pertaining to maintenance from the traditional sources, in their original formats (e.g. data log from a SCADA system, a drawing from a CAD repository, etc.). The second, instead, relates to the ways the data gathered can be translated (real-time and autonomously - without user intervention) into the virtual contents required by the AR system. While the first issue depends on the state-of-the-art of the maintenance systems used by companies and accessed by the purpose of AR, a solution for the second issue can be provided by algorithms and middleware that can enable this kind of integration. For MCAR system this issue is less relevant because users, rather than software, are appointed to augment the reality and so they are entitled to search on PCs the information needed. Even in this case, however, some complex contents, in particular 3D images, virtual components and so on, could be needed; hence, they must be generated and/or extracted from other systems and uploaded to the AR software in advance. For this purpose, future research needs to define the data structure that is most suitable for exchanging this kind of information, and the way for integrating different systems in order to extract automatically the necessary contents.

4.2 Organizational issues

Informant A identified some preconditions for favouring the introduction of AR in industrial companies. Firstly, this adoption must be evaluated at the light of a detailed cost/benefit analysis that should consider if the organization needs this kind of technology, how service delivery process is impacted, how resource are saved and so on. In other words, the introduction of AR should be feasible from both a technical and economic point of view. With respect to Alpha, for instance, MCAR systems have been considered as a way to simplify maintenance tasks, improving the efficiency and effectiveness of the intervention. In addition this technology has been pointed out as a great opportunity to reduce the highly costs related to the deployment of skilled technicians. Secondly, the mindset of people and, therefore, the innovation pace of the organization should be considered, since it could greatly favor or, conversely, impede the adoption of this technology. In fact, the openness or not to innovation and new technology is a crucial factor for the acceptance of new methods in providing the same outputs in a better way. Informant A actually, perceived that the mentioned organizational issues could prevent, if not properly managed, the rapid spread of this technology in maintenance and in services, rather than the technical issues describe in the previous section. In fact, these are strongly believed by the national service manager, to be overcome in the next years. Similarly, the amount of investments that up to now is not negligible is believed to decrease as a wider utilization will lead to the down pricing of displays, microprocessors, etc.. Another interesting consideration by Informant A concerns the modification to the service delivery system that could derive from a more effective distribution of knowledge from R&D centers to the field. Informant A, indeed stated that the introduction will

"change significantly when and how to train and so the kind of skills distributed on field and in back office".

This definitively impacts on the design of products and processes. With the use of MCAR systems, in fact, it is possible to redesign the service delivery system introducing a high skilled central help desk to support field workers. Hence, the workforce will be productive even with simplified training programs. In this scenario, of course, the relations with labor unions need to be carefully considered. Finally, Informant A highlighted the possibility to use these systems also to support maintenance tasks on low complex products, where the AR user could be the final user i.e., the product operator.

5. CONCLUSIONS AND FUTURE WORK

This paper presented the results emerged from a case study dealing with the possibility of use MCAR systems in real industrial contexts. Technical and organizational issues that can limit the actual introduction of this technology were identified and discussed. Despite several other factors should be considered before making a final decision, the authors believe these technologies are directed, within a few years, to become a standard equipment of service and maintenance department. In order to be ready as soon as the technological limits will be overcome, it is therefore necessary to understand the feasibility of this technology through demos, simulations etc. that involve all the interested workers and stakeholders (such as managers, technicians, product specialists, labor unions, etc.). This could be even an occasion to rethink the service delivery system, i.e., the way services are delivered.

Two main limitations can be identified in this work: on one hand it takes into account only a specific maintenance scenario, in which only a particular type of AR technology (i.e., MCAR) can be eligible for introduction. On the other hand, only a case study has been carried out. Furthermore, since this technology is not so spread, the company studied is not actually using it. Therefore, several efforts were required to prepare the context for the demonstration.

Further research is claimed to address: i) the investigation of other maintenance and service scenarios and implementing other AR systems, for instance, the use of online mode AR for routing maintenance or for telecontrol; ii) the conduction of retrospective case studies in firms that are adopting or have already adopted these kind of systems in order to evaluate how they faced or are facing the related challenges.

6. AKNOWLEDGMENTS

This paper has been inspired by the activity of the ASAP Service Management Forum (www.asapsmf.org), Italian community where scholars and practitioners collaborate in developing research and technology transfer in the field of service management and PSS.

The research leading to these results has received funding from the European Community's FP7/2007-2013 under grant agreement n° PIRSES-GA-2010-269322, ProSSaLiC Project.

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