# AUGMENTED REALITY AND MOBILE TECHNOLOGIES FOR MAINTENANCE, SECURITY AND OPERATIONS IN INDUSTRIAL FACILITIES

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## ABSTRACT

Safety issues are a crucial aspect in industrial plants management due to regulatory, operational as well as strategic aspects. It calls for tools that could be easily embedded into everyday practices and able to combine complex methodologies with high usability requirements. In this perspective, the proposed research work is focused on the design and development of a practical solution able to integrate augmented reality and wearable technologies for operators' support in complex man-machine interactions. After establishing both functional and non-functional requirements, a structured design strategy has been adopted. The main outcomes of the aforementioned strategy include a multi-layered modular solution (developed at MSC-LES lab of University of Calabria) whose potentials are investigated through two different case studies and technical equipments.

**Keywords**: safety, security, maintenance, industrial plants, augmented reality, mobile technologies, wearable systems

## 1. INTRODUCTION

Safety and security issues are one of the major concerns in industrial plants. Due to the greater public exposure and to the increasing attention of current regulations, plant managers are concerned with workers' health and safety more than ever before. As a matter of facts, workplace accidents are likely to receive a great deal of media coverage as well as to activate legal investigations into companies' liabilities. Both ways, irrespective of actual faults, the reputation of the company involved may be damaged and misjudgment/misrepresentation could seriously damage the brand image. These are the reasons, among others, why the management is usually prone to adopt all those countermeasures that can contribute to risk factors minimization and control. In addition to safety and security, also maintenance operations play a critical role for the efficiency and productivity levels and they are often connected to safety and security issues.

In this framework, the main research contributions already available in literature fall under the following categories: models and methodologies, methods and tools. What has been done in terms of models and methodologies include mainly risk estimation (Okabe and Ohtani, 2009; Ahmad et al., 2014; Sengupta et al. 2016) and risk analysis (Tixier et al., 2002; Reniers, 2009). Besides, a state of the art review on risk assessment methodologies and analysis tools is proposed by Khan et al. (2015) while uncertainty in risk assessment for high-consequence technologies is treated in Zio and Aven (2013).

As for methods, the main effort is toward practical approaches for risk reduction taking into account even economic and regulatory aspects (Segawa et al., 2016). Basic requirements for a successful risk reduction strategy can be found in Summers (2009) while process safety management has been covered by Knegtering and Pasman (2009) and critical challenges in implementing safety programs are addressed by Qi et al. (2012) without neglecting the capability to recover from disturbances (Dinh et al. 2012).

In terms of tools, it is worth mentioning the contribution provided by Shariff et al. (2006) where risk assessment is integrated into process design utilities.

This quick and short analysis of the literature shows that there is a gap in the development of operational tools. To bridge the gap, this research work proposes a new approach where augmented reality and wearable smart technologies are seamlessly integrated for safety & security enhancement as well as to support maintenance operations. The basic idea is to support operators in complex, real time man-machine interactions. In this perspective augmented reality can provide visual, self-explanatory information on how to execute a specific task/procedure as well as demonstrate the best interaction patterns.

However, it goes with the need to preserve operational efficiency without hindering operators' workability. For this reason, the proposed approach involves smart wearable technologies aimed at ensuring great flexibility in terms of freedom of movement. For instance, using smart glasses operators can have their hands free for executing their tasks while they access the system functionalities. Therefore, the many possibilities offered from wearable technologies have been investigated to detect the most suitable system configurations and to ensure a successful deployment at operational levels.

The reminder of the paper is organized as follows: section 2 illustrates the system functional requirements, section 3 presents the design approach, section 4 gives an application example and lastly conclusions are drawn.

## 2. SYSTEM OVERVIEW AND REQUIREMENTS

The system is built upon the need to ensure the following capabilities:

- Provide operators with real time feedbacks and augmented reality contents on task/procedures execution so as to minimize the risk of accidents and support training.
- Monitor men-machine interactions with augmented reality for safety enhancement.

Other non-functional requirements of the proposed system include: usability, interoperability with legacy systems, manageability, and regulatory compliance.

To fulfill such requirements the architecture depicted in figure 1 has been designed.

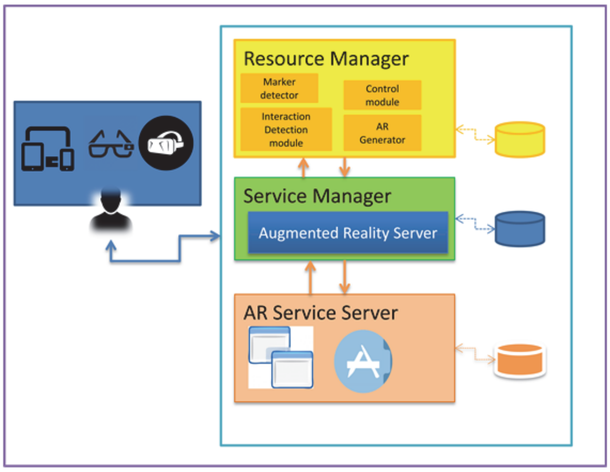

Figure 1: Architecture overview

Basically, this architecture is scalable and modular in nature since the underpinning principle is the separation of the service infrastructure from the contents base. The service infrastructure includes the service manager implementing the interactions with the Augmented reality server and the AR Service Server that fulfills users' requests sent via mobile or wearable technologies.

On the other side, the Resource manager is responsible for contents and metadata.

Furthermore, considering that the tool is envisaged for deployment at operational level, a user-centered design approach has been pursued. Bearing in mind that end-users may not have advanced technical skills, usability issues have been widely explored.

In particular, along the development cycle, usability tests have been executed over the main interaction components to detect and fix usability problems. From a conceptual point of view the architecture depicted in figure results in the following functionalities for its intended users:

- let operators acquire advanced contents based on augmented reality about man-machine interaction procedures compliant with safety standards and principles.
- preliminary training for tasks with high risk factors.
- support operators providing information that is usually not available in the workplace (i.e. machine productivity, expected maintenance operations).
- send warning messages about the outcomes of improper operations (i.e. what happens if a maintenance operation is not performed, it the operators fails, etc).

## 3. SYSTEM DESIGN AND IMPLEMENTATION

To conceptualize the system requirements, for analysis, design and implementation purposes, UML diagrams have been drawn up.

As a matter of facts UML diagrams allow depicting both the static structure of the system as well as its dynamical behavior over time. Structure diagrams have supported the identification of the system components and relations at different levels of abstraction. In particular the structure diagrams that have been drawn up include the class diagram and the model diagram depicted in figures 2 and 3 respectively.

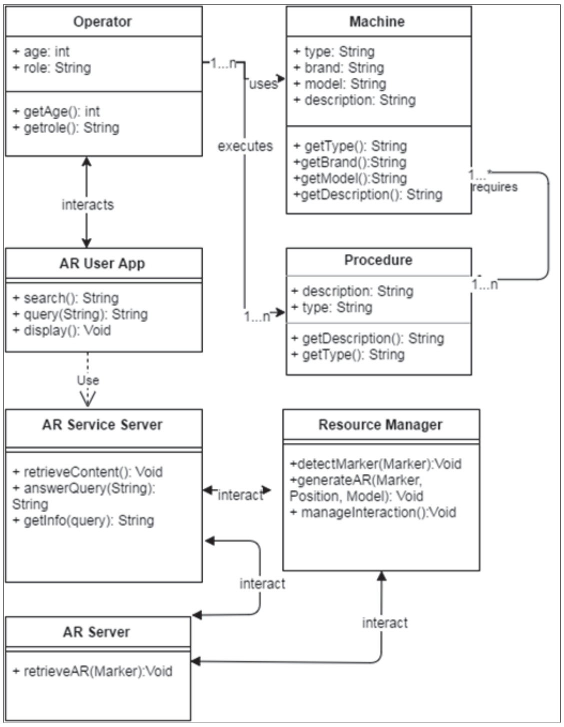

Figure 2: Class Diagram

The class diagram highlights the structure of the system in terms of classes, interfaces and related constraints, features and relationships.

Therefore it shows and describes the application domain of the system: operators with specific roles are called to interact with one or more machines executing one or more procedures; in doing so they can be supported by the system that is required to provide AR contents as well materials about machines and procedures.

To this end, the system font-end application interacts with an AR Service Server that activates a set of methods needed to collect/retrieve contents. The AR Service Server, in turn, interacts with the AR Server that implements AR algorithms and with the Resource Manager that is responsible for contents (data, metadata, models, multimedia, etc) handling .Furthermore, a complementary view of the system is given in the model diagram that is quite useful to give new insights about architectural, logical and behavioral aspects. The model diagram related to the system is represented in figure 3.

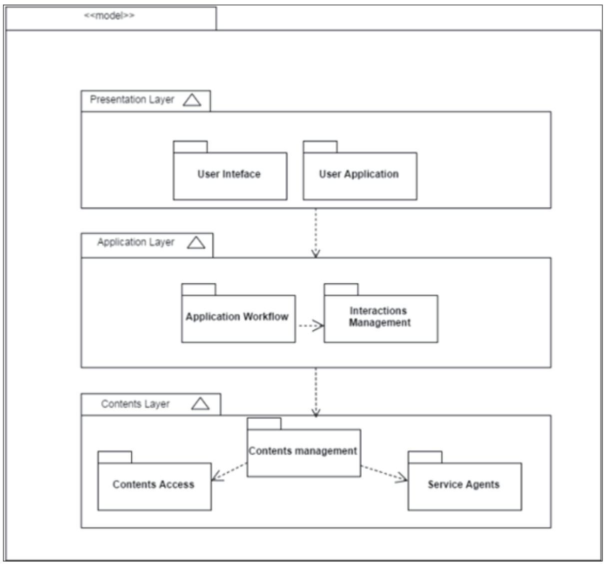

Figure 3: Model Diagram

Here, the overall model has been broken down into three main layers. The presentation layer includes interfaces and applications on the user side and is devoted to ensure that the contents passing through are in the appropriate form for the recipient providing also interaction mechanisms (i.e. access to video, 3d representations of a particular machine, documents, etc). The application layer implements the core functionalities of the system and the logics in order to met both functional and non-functional requirements. The contents layer, instead, provides access to all those contents (information, multimedia, geometric models, metadata etc) that are needed to let the system deliver meaningful information to its intended users. As mentioned before, the system evolution over time is represented by behavioral models, namely the use case diagram, the state machine diagram and the sequence diagram. As shown in figure 4, the use case diagram highlights what the system is supposed to do (requirements) and what the system can do (functionalities).

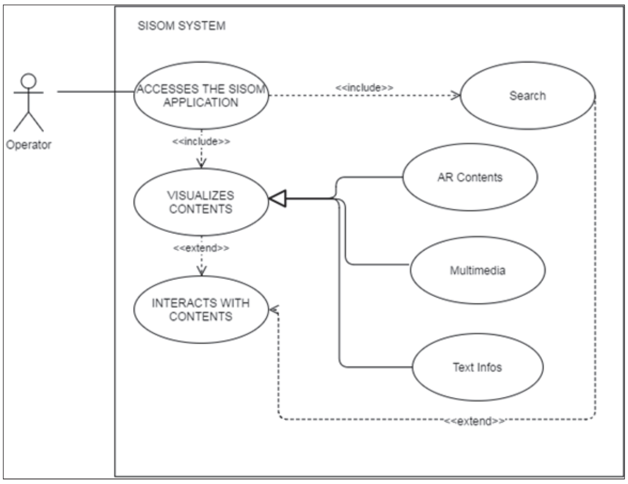

Figure 4: Use case diagram

In particular, the set of actions that the operator can do while accessing the system font-end application include: contents visualization (i.e. pointing his device toward the machine he is supposed to interact with) and/or search among the available contents.

After contents are displayed the operator can freely interact with such contents through his own device. Contents may be information, augmented contents, multimedia or a combination of the aforementioned content types.

Systems transitions and states, instead, are considered within the state machine diagram (Figure 5) that is particularly useful to understand how interaction patterns can evolve. Since transitions and states are mainly due to the user choices it is possible to ascertain that the system is event-driven in nature.

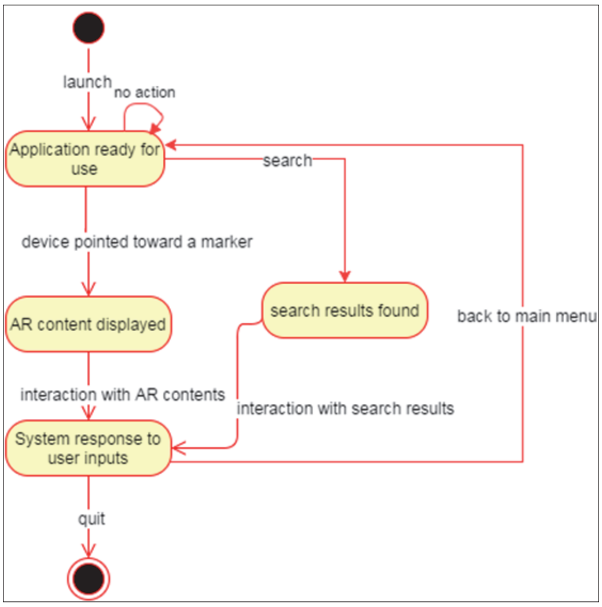

Figure 5: State machine diagram

As for messages exchange, the sequence diagram has been drawn. It is a useful representation of how the main system objects interact as well as of the communication exchange showing that it is mainly synchronous in nature.

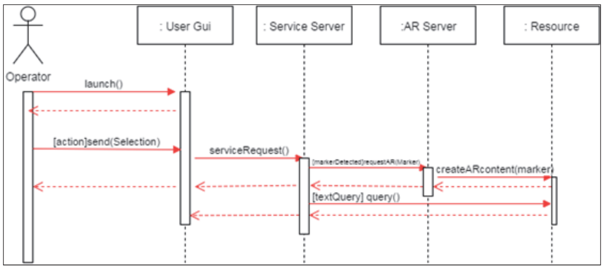

Figure 6: Sequence Diagram

Therefore the system design has been carried out according to a structured approach based on well-organized elements of solution adopting a "divide and conquer" strategy where the overall solution puts together multiple solution modules communicating each other.

## 4. APPLICATION EXAMPLES

The MSC-LES lab (University of Calabria) lab has a long experience in developing system and solutions based on 3D Virtual Environment and Simulation in different areas such as Industry and Logistics (Longo 2013; Longo et al. 2015). Therefore the step ahead in this project was the integration of new methodologies together with mobile and wearable technologies.

To test and show the potentials of the proposed solution the system has been deployed in two different use cases: one is about the use of a control panel and the other is about the installation of an hydraulic pump. For each use case, different fruition experience have been investigated. Considering the control panel use case, regardless of the device used by the operator, the front-end application is able to display augmented reality contents superimposing different levels of information.

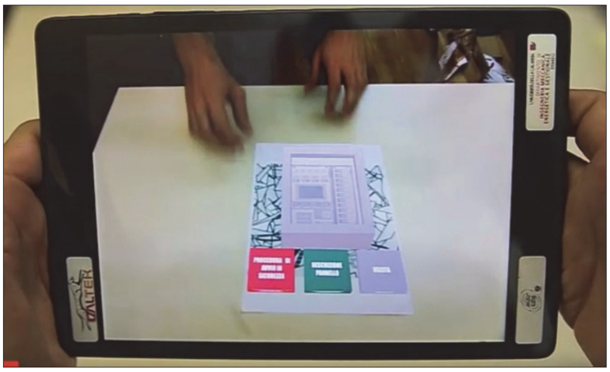

Figure 7: Control Panel use case

A first example is shown in figure 7, where augmented reality contents are displayed through a tablet over a marker and include a 3D representation of the control panel as well as three buttons giving access to :

- The security procedure for operations starting;
- The description of the panel commands;
- The function to go back to the application main menu.

It is worth noticing that the same functionalities can be also accessed using different technologies.

As a matter of facts, instead of using a tablet, the operator can get access to the same functionalities using a headset (i.e the Samsung Gear VR) for contents display and a gesture control system like Myo Armbands for interaction purposes such as pressing the button to display the control panel commands description (as shown in figure 8).

Figure 8: Solution deployed through headset and armbands

In addition, another solution for the system fruition, include an helmet with a monocular eyewear and a gesture control system interfaced with an interactive whiteboard (Figure 9).

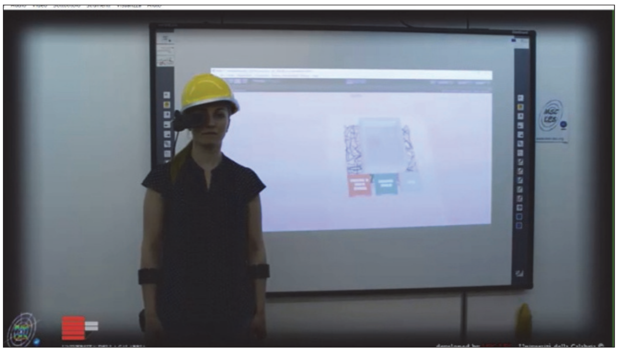

Figure 9: Solution deployed through helmet, monocular eyewear, armbands and interactive whiteboard

As shown in figure 9, AR contents are projected over the interactive whiteboard and interactions occur through a gesture recognition system implemented within armbands.

In this configuration the system is suitable for training purposes such as teaching security procedures to newcomers or let experienced operators get into new safer procedures.

For the same purpose, a lighter solution where the helmet is replaced by smart glasses has been set up (Figure 10).

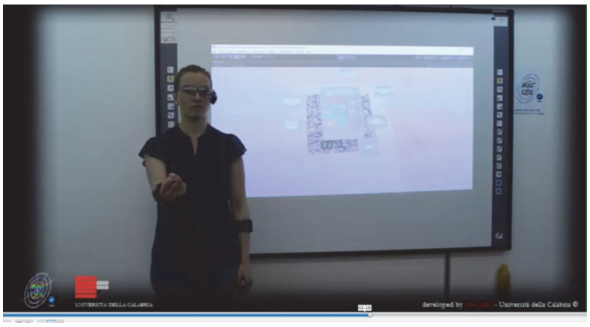

Figure 10: Solution deployed through smart glasses, armbands and interactive whiteboard

After all, to take the solution a step further, an additional effort has been made to search for an overall more convenient configuration in terms of deployment at operational level (see Figure 11). To this end, firstly a solution to use the panel as marker for its own augmented contents is under investigation and afterwards, an ergonomic analysis will be performed over the basic configurations described above to detect the most suitable one so as to preserve both the operator comfort as well as his operational efficiency.

Figure 11: Examplw of deployment in place

As for the second use case, it is about the installation procedure of an hydraulic pump (Figure 12). The whole procedure has been broken down into four steps and each step has been faithfully recreated in the AR environment.

Figure 12: Hydraulic Pump use case

Upon interaction between the user and the AR commands, specific functions are activated to allow the virtual reality animation of the basic operations required to fulfill each step (Figure 12).

Figure 13: Detach/Attach the main pump body

Hence, using the app, the operator can view how to perform each step pressing the related AR button (see Figures 13 and 14).

Figure 14: Detach/Attach the pump manometer

## 5. CONCLUSIONS

The proposed research discusses about the conceptualization and development of an advanced tool for safety enhancement in industrial plants. The proposed tool is meant to support operational processes with a particular focus on those tasks affected by high risk factors. To this end, special attention has been paid to the design process carried out according to a structured strategy. Structured and behavioral diagrams, have been drawn up to specify the main requirements and provide a multi-layered representation of the solution. Furthermore, after implementing the technical architecture, the solution deployment has been investigated in two application examples where different configurations, in terms of technical equipment for contents fruitions, are considered. As a result, the proposed tool is able to deliver real-time augmented reality contents to support men-machine interactions as well as complex operational procedures. Two main use patterns have been envisaged:

- a daily tool for support at operational level
- a training tool for newcomers or for experienced operators that have to learn new safety procedures.

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