SMART MAINTENANCE

An Augmented Reality Platform for Training and Field Operations in the Manufacturing Industry

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Sommario

Executive Summary

This document discusses a selection of Inglobe Technologies solutions for the development of an Augmented Reality (AR) platform which is appropriate for both training and operations in different industrial maintenance scenarios. The technology presented here can be employed in complex scenarios and tasks like, for instance, assisting technicians on the field in their job of fixing equipment and machines.

AR applications provide a technology that has the potential to support and speed up training, while at the same time increasing performance and effectiveness levels. Some statistics suggest performance improvements up to 30% with involved employees reporting higher levels of engagement. Applications of AR that support technicians in the field have the potential of reducing costs up to 25% throughout quicker maintenance or component substitution, identification and setup of new connections, solution of faults and misconfigurations, with less burden on backend personnel and system resources. Additionally, thanks to the information that operators collect on the field, the AR technology contributes to an improvement of the quality of enterprise data.

Development of AR applications in an industrial setting is a complex task, made even more challenging by the need to leverage the full power of native platforms (iOS, Android, Windows Phone). This is certainly the case of modern, cutting edge AR mobile applications. Inglobe Technologies simplifies this complex task by providing software components, technology, expertise and customizable solutions that help managing complexity with reduced time from requirement analysis to deployment.

In order to present and educate on the software components needed to develop an effective AR solution for industrial maintenance, the document offers an overview of the challenges, enabling technologies and required solutions.

The document also clarifies how, according to Inglobe Technologies, the adoption of an "AR strategy" (i.e. a strategy for the introduction of AR for industrial maintenance), is not a consequence of an improvised choice, but rather the result of a path that requires the definition of a Roadmap for the development of Enterprise class AR solutions.

In the remaining part of the document we discuss the challenge of making industrial maintenance more efficient under two main respects, i.e. the intelligent support of field force operations and training (section 1); in the same section we discuss the dimensions from which the need for developing a "Smart Maintenance" solution derives; in section 2 we introduce the technologies that enable AR solutions for maintenance, including positioning technologies, pattern recognition, tracking and artificial vision as they allow to create effective and improved industrial solutions; in section 3 we offer an overview on the architecture of the proposed solution; soon after, a generic use case which is relevant in this context is discussed (section 4); in section 5 we discuss an approach to estimate the ROI (return on investment) by clarifying the reference parameters for evaluating quantitatively the benefits that the adoption of an AR strategy for maintenance provides; finally, in section 6, we offer an approach and Roadmap for the design and implementation of an enterprise class industrial Augmented Reality solution.

1. Introduction

Assembly of equipment and maintenance of industrial machinery are complex tasks that require substantial resources both for training and for operations. In this context, one of the most challenging problems is how to make those processes more efficient and robust. An effective approach is to rely on a set of emerging technologies, such as Augmented Reality, that are currently reaching maturity in many industrial domains.

The term Augmented Reality (AR) refers to a bundle of technologies that allow the overlay of additional layers of digital information onto the objects and processes in the real world. These layers of information are contextually accessible in real time by means of suitable computing and visualization devices. Devices for AR not only include PCs, laptops, smartphones, tablets but also new generation wearable devices such as a variety of AR glasses (e.g. the bespoke Google Glass). A property of AR systems is to make hidden information visible and accessible whereas it is normally inaccessible and opaque to human senses.

The fact that Augmented Reality improves the efficiency of industrial assembly tasks has been demonstrated in a number of studies. In the context of a finnish study (J. Saaski, T. Salonen, M. Liinasuo, J. Pakkanen, M. Vanhatalo, A. Riitahuhta, "Augmented Reality Efficiency in Manufacturing Industry: A Case Study", Norddesign 2008 conference, Norddesign 2008; 99-109), two groups of operators have been trained to accomplish the task of assembling a small engine; the first group had been trained by using standard paper instructions, whereas the second group had been trained by using augmented reality instructions provided to operators by means of a suitable head mounted display equipped with a video camera. Results of the study show that, in the context of this kind of use case, employing AR instructions entails an increase of the speed in the execution of the task of 17% compared to the use of paper instructions. The study also shows that, in the case of paper instructions, the probability of using the inappropriate tools was six times higher than in the case of AR instructions. Similarly, the attempts to put a piece in the wrong place with paper instructions were twice with respect to AR instructions. All the differences in the two use cases were found to be statistically significant.

On the one hand, it is widely accepted that the traditional training methods require to carry out numerous hours in classroom activities in combination with a small number carried out in the field. The latest training methodologies that make use of new immersive techniques (situated learning, augmented reality, immersive and blended learning[1] etc.) which in other fields have

[1] The term "situated learning" refers to a learning model according to which learning takes place directly in the same context in which it is applied. According to this view, learning should not be seen as the mere transmission of abstract and decontextualized knowledge from a teacher to a learner, but rather as a process of co-creation that takes place in a given physical and social environment (J. Lave and E. Wenger (1991) Situated Learning. Legitimate peripheral participation, Cambridge: University of Cambridge Press).

shown an improvement of performance compared with traditional methods, are now slowly spreading also in the industry. Their potential impact on the improvement of efficiency and on the reduction of costs is not yet fully exploited.

On the other hand, it is also known that, to date, maintenance operations in the field are carried out by relying exclusively on the skills already present or acquired by maintenance personnel during the planned training activities of the company. Carrying out maintenance operations on complex industrial machinery often challenges the cognitive and operational skills of the personnel. In many circumstances, in fact, even if the operator has been trained adequately, maintenance tasks may require the consultation of sheets, technical manuals, or even to rely on remote assistance. All the additional activities that are necessary to collect information needed to finalize a tasks take time and, for this reason, have a substantial cost.

Based on what we have said above, the need emerges for the companies to adopt tools adequate to:

1) ensure the improvement in efficiency and learning performance of the maintenance personnel
2) help reduce the maintenance costs of the machines
3) maximize/increase safety and minimize human error
4) provide an extensive and more effective support to the customer.

In this context, the goal of the Smart Maintenance solution is to provide companies with a set of tools, based on cutting edge Augmented Reality technologies, ubiquitous and connected to enterprise backend, to support maintenance operations of material assets, like, for instance, machinery, plants or anything else, in the field.

Figure 1. Example of Augmented Reality on an industrial plant

2. Augmented Reality and other Enabling Technologies

In this section we introduce the most important emerging technologies, many already developed and running, which are essential to address the challenges described in the previous section.

2.1 Location and Positioning Technologies

The term "Positioning Technology" refers to solutions that respond to the need of identifying as accurately as possible the location of individuals or objects within a given environment. The operators can be located in a closed environment, circumscribed, and whose characteristics are known (as, for example, a warehouse or a hospital), or in an open space, such as a city district or an industrial site.

2.1.1 Outdoor Positioning Technologies

The most common positioning technology for outdoor use is the GPS (Global Positioning System). Traditional GPS systems suffer from a number of limitations. For example, standard GPS can be recommended only if you do not require a precision of an order less than 5-20 meters. For best results, one option is the Differential GPS (DGPS), which relies on a network of broadcast stations fixed to the ground that correct the error of the positions of the satellites. The precision of DGPS within 100-300Km from a transmission station may be up to 5-10 cm. The accuracy of DGPS makes them an excellent tool for applications in the aerospace, defense and surveying. Their application can certainly also be imagined in the context of the development of innovative training and industrial maintenance systems.

A different solution for outdoor positioning is the WiFi positioning. This technology allows us to estimate the position of an object endowed with a wifi antenna based on the knowledge of the location of a number of WiFi access points in the neighborhood. Under the principle of triangulation of hotspots signals, these systems can identify the location of an object with an accuracy of between 5m and 100m, depending on the density of the available hotspots.

Figure 2. Some of the technologies that make indoor and outdoor positioning more accurate for industrial applications

2.1.2 Indoor Positioning Technologies

Because of the attenuation of the signal, the GPS / DGPS are not used to detect the position of the operators or assets in indoor environments. There are, however, alternative methods for achieving the same purpose.

In this case, the WiFi positioning is still a viable option. Using the same principle of outdoor WiFi positioning, but thanks to a more accurate knowledge of the electro-magnetic field, indoor wifi hotspots and their relative distances, the best implementations can achieve an accuracy of around 1m. It's important to note, on the other hand, that the configuration of an accurate indoor localization with this system may require a laborious calibration phase. In some cases the process can be automated, but the accuracy always has a greater cost. In addition, any alteration of the magnetic field can affect the precision of the identification of the location, and in some circumstances, require a recalibration of the system.

Other solutions for indoor positioning can be built on the basis of RFID (Radio Frequency Identification) tags and readers, optical (e.g. Infrared, LED) and acoustic systems (e.g. ultrasound) as well as a combination of RFID and WiFi and WiFi + LED. Once the transmitters are active and the signals are received by an appropriate receiver, the indoor positioning system performs all the necessary calculations necessary to locate the operator or an asset within the environment.

Indoor positioning can also be realized by means of appropriate techniques of artificial vision and pattern recognition. The simplest solutions leverage the prior knowledge of the 3D structure of an environment (or object to be observed) and the use of markers (i.e. markers with regular shapes, such as QR code-like markers) associated with specific points of the environment or objects. The markers encode location data and then are used to retrieve information associated with a point and its surroundings. An implementation of this same principle, more complex from the computational point of view , employs the 3D structure of the environment or object , together with specific landmarks or visual stimuli; this approach leverages the physical or geometric characteristics of the environment and then uses computer algorithms to determine the direction of the point of view of the camera and estimate the position of the user in the same environment. This requires that semantically relevant information is contained in some manner in the video stream (see also Recognition and Tracking Technology), like, for instance, the parts of an engine that need to be repaired.

Finally, it is worth mentioning that the use of autonomous systems, such as robots equipped with cameras and machine learning algorithms that move in three-dimensional space, has shown that it is possible to capture, fast and accurately, the 3D structure of an indoor environment. This approach is particularly useful when the environment, in which the AR support system is used, needs to be mapped and be known in advance.

2.2 Recognition and Tracking Technologies

Not only are the environments closed or open (indoor and outdoor), they may also be known or unknown. In the latter case, the characteristics of the environment must be learned by an artificial system with specific techniques in order for it to be able to support operations.

2.2.1 Pattern Recognition

When the attributes of a space are known, a set of recognition technologies allows to identify an object, be it a person or an asset, as well as to retrieve all the information associated with that same object. Recognizing a person or an asset in real situations can be a very complex task, especially when the environments change or evolve over time, due to human or natural factors.

In order to overcome these difficulties, several "pattern recognition" techniques have been developed. The principle behind the most effective proposals is to find the invariants with respect to the transformations that the object or the environment that needs to be recognized undergoes, as for example scale invariant and illumination invariant geometric shapes.

One of the technological solutions proposed in the research to solve this invariance problem is the use of artificial neural networks - for example in a combination of ART (Adaptive Resonance Theory) [3], Back-propagation and Recurrent Architectures. Another solution is based instead on the isolation of specific characteristics of the objects that change at a slower pace compared to those that change fast in the environment, such as the edges or contours of an object.

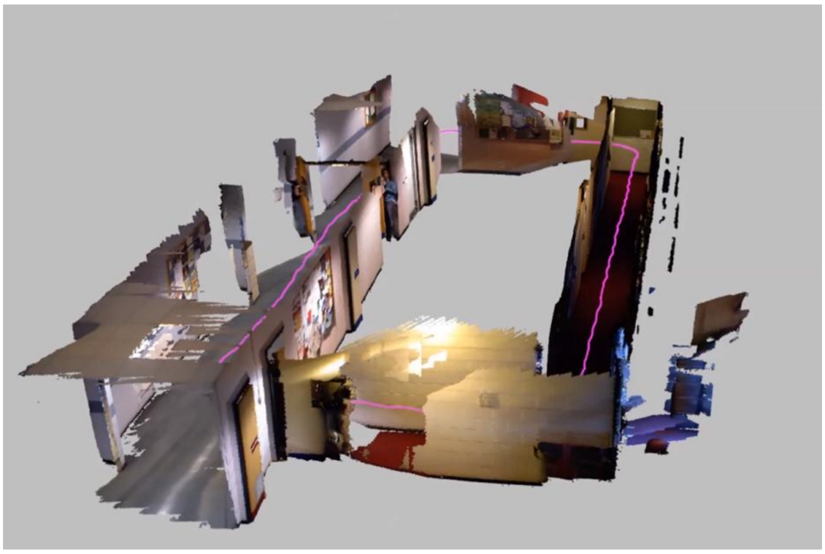

Figure 3. The environment in which the AR experience takes place can be mapped with semi-automated methods and then recognized. (http://tinyurl.com/pradoh4)

[3]Adaptive resonance theory (ART) is a theory developed by Steven Grossberg and Gail Carpenter regarding the way the brain processes information. It introduces a number of neural network models inspired by the idea that the identification and recognition of objects in the real world are the result of the interaction between observer's high level expectations and low-level sensory information (S. Grossberg (1987), Competitive learning: From interactive activation to adaptive resonance, Cognitive Science, 11, 23-63).

2.2.2 Tracking

The recognition and the detection of the fixed position of an object in a given environment may not be sufficient for certain purposes, as for example when it is necessary to precisely know also the direction and orientation of its movement within the environment from the point of view of the observer. This kind of information is strictly required when operators need to access to relevant data in real time in a given application domain, such as when they need to repair a fault of a system.

Tracking for AR is the act of continuously identifying the position and orientation of an observer's viewpoint with respect to a given 3D reference system over time. Tracking can be approached using one of three methods and a hybrid of techniques:

- Active tracking methods rely on sensors that are taking readings via a beacon/receiver system that must be supplied with power (e.g., depth sensing with infrared or laser, ultrasonic, GPS, WiFi).
- Passive tracking does not require use of power to emit or receive a signal. These are based on inertial sensors (e.g., accelerometer, magnetometer, gyroscope).
- Computer vision (optical): this covers both marker-based, natural feature tracking approaches.
- Hybrid Tracking methods that combine inertial and computer vision-based techniques.

It is important to note that positioning and tracking technologies overlap with the main differences being that tracking must also:

- Register with the real world in 3 dimensions and
- Identify changes in the position and orientation of the user's viewpoint in time, using positioning sensors.

For professional users in industrial settings, it is most useful to make distinctions between 2D tracking, 3D tracking and Hybrid Tracking.

2D Tracking

Standard GPS and inertial sensors alone cannot provide accurate tracking information due to issues like noise affecting transmission and drift over time. The majority of the commercial solutions currently available in the market suffer from this limitation. It has also been argued that visual recognition and optical tracking might turn to be useful in the use cases being explored, but current solutions mainly employ marker based or 2D natural feature recognition and tracking techniques (NFT) to identify and track patterns in the environment. It is well known that marker based approaches suffer from many limitations, like for example the high sensitivity to lighting changes, or the limited tracking range. 2D NFT approaches are more robust under certain respects but they are slower than marker tracking and are not still a solution that works in many important scenarios.

3D Tracking

Different marker-less tracking solutions have been proposed in the research and are in the process of being adopted in the context of industrial solutions. An important class of solution is based on 3D Tracking. The difference between 2D Tracking and 3D Tracking is that the features tracked by 3D tracking algorithms are not just features in a 2D space, but features in the 3D space. The most developed approaches include edge based tracking and template based tracking, just to mention a couple. The idea here is to use features that are already present in the environment to extract information that is useful for tracking.

Edge-based techniques are based on processing algorithms that are able to identify object boundaries and edges in the camera stream. The edges are then matched towards previously available 3D models to get the correct pose of the camera with respect to the object (e.g. RAPID, one of the first edge-based tracking approaches ever introduced - C. Harris, Tracking with Rigid Objects. MIT Press, 1992).

Template-based tracking is another interesting solution when it comes to tracking real objects using a camera. A template refers to the combined set of projected model features and its corresponding position parameters of the model with respect to user's viewpoint. Large number of templates are created by projecting a 3D model in an off-line process providing a discrete approximation of the correct observer's viewpoint. This allows to understand where the observer viewpoint is based on the matching with the available templates and the images.

Hybrid Tracking

In many circumstances, the use of a single tracking technology may result not to be viable. In these circumstances, a suitable combination of optical and inertial tracking methods can be a solution. This allows the continuous tracking in conditions in which the environment information is so sparse that none of the methods above, in isolation, would work in a satisfactory manner. Applications based on these approaches are currently under development in areas related to safety and maintenance.

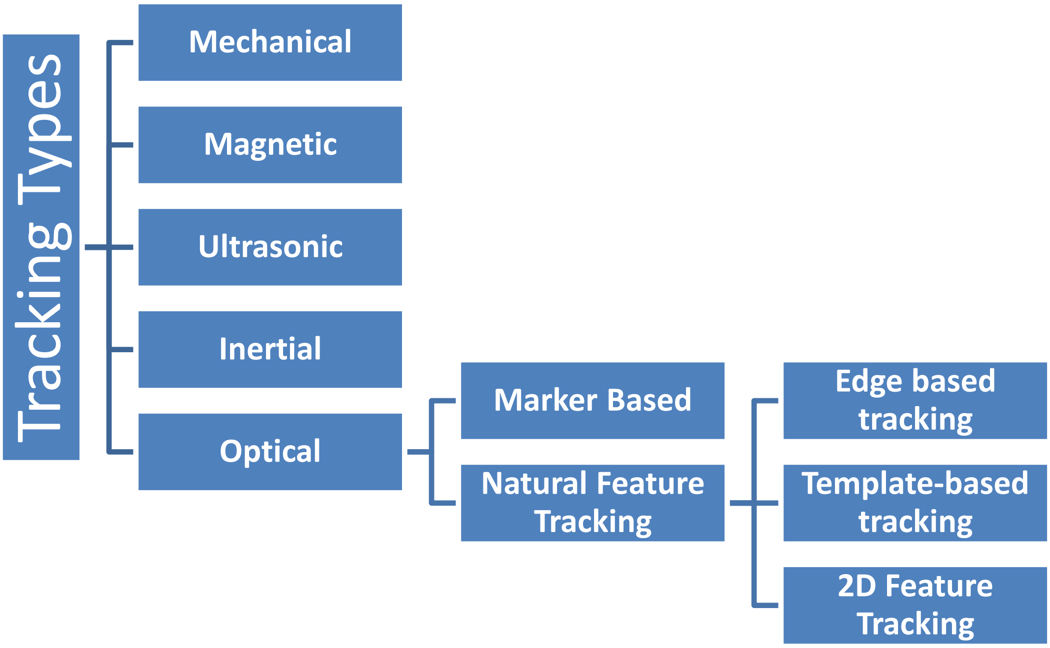

Figure 4. Taxonomy of AR tracking

Integration with existing data infrastructure

Once integrated into a mobile application, the technologies described so far allow to introduce an intelligent AR support approach in complex business environments. When the support systems need to access the data stored in the enterprise backend, the AR solutions, resident as native applications on mobile devices, can be integrated with the existing IT systems within the organization. The data collected and maintained by the services related to enterprise backend can be used to guide field workers in real time. This requirement poses two main problems: 1) a technique relating to the infrastructure required for the integration of mobile applications with enterprise backend, and 2) the methods of analysis, simulation, synthesis and presentation of data in such a way that they are optimized for use in AR applications. In both areas, the involved technologies and methodologies have long since reached the maturity.

3. Overview on the Smart Maintenance solution

Smart Maintenance is the platform of Inglobe Technologies for the maintenance of industrial machines . The platform includes three main components:

1) Content Management Layer
2) Application Frontend
3) Administration Backend

The Content Management component contains all the tools required to create content suitable for AR visualization based on the 3D models and related assets of the company. It consists of two different parts: a) one or more custom plug-ins that are directly connected to specific CAD software and b) a web-based interface through which users can organize the maintenance activities and tasks and add content to be viewed on the mobile application.

The Application Frontend also consists of two main parts:

- Administration Web Client: allows users to create different maintenance sessions and scenarios, add users and roles, create and locate the task and the information available in a given operational context , assign tasks to users, add data and multimedia content for display during AR visualization. All information is updated through a web based interface and stored in an RDBMS on a server in the corporate intranet or in a cloud server.

- Mobile User Client: Allows the operator to access to the assigned maintenance tasks as well as to all the contents and procedures shown with the use of Augmented Reality. The mobile client allows users to download and view all the information needed for a maintenance operation where they need it and when they need it. Two important components of the mobile user client are the management of specific content in the maintenance scenario and the access to the tracking of objects relevant to maintenance.

An overview of the architecture of the solution is shown in the figure below.

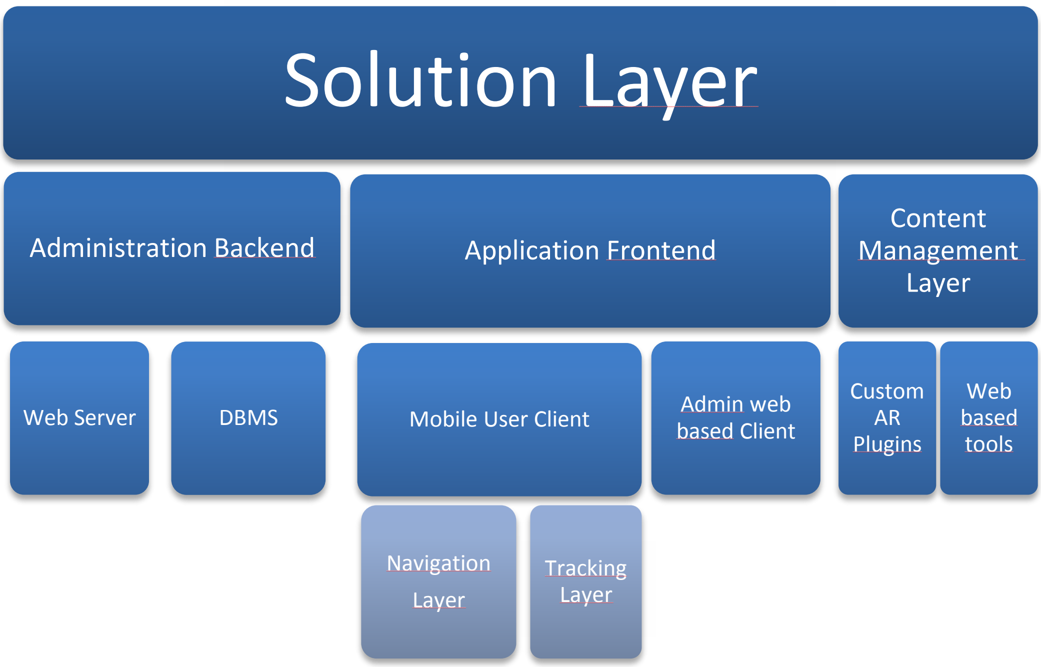

Figure 5. Overview of an "Enterprise Class" AR support system for Training and Field Operations for maintenance.

3.1 Software Components

A description of the different software components, including the AR technology core components, and required development skills is offered in the following Table 1:

NOME DEL COMPONENTE	DESCRIZIONE DEL COMPONENTE
Application Frontend	Communication interfaces and services shared by the mobile and administration clients. Customized based on requirements*
Mobile User Client	Business Logic, Interfaces, Communication Services of the mobile App, customized on specifications *
Visual Search	Captures camera images and finds the closest image in a database; eventually reconstructs user's viewpoint
Navigation Layer	Reads sensors and visual information to provide user location, indoor and outdoor
Sensori Mobile	GPS, Accelerometer, Gyroscope, Compass
Codici QR	QR codes can be employed to convey information relevant to localization
Image based search	See "Visual Search"
Multiple 3D Point Clouds	Estimate the user's position through the analysis of the 3D structure of the environment by using different point clouds associated with different portions of the environment. It's a unique and advanced feature of Inglobe's 3D tracking Engine
Tracking Layer	Allows to identify and track objects in the environment
2D NFT	Tracking generic 2D pictures, also "on the fly"
Marker Based	Tracking B/W black border square markers
3D Tracker	Tracking real 3D objects: an advanced feature and addition to the basic tracking methods
Admin Web based Client	Component that allows web administration. Customizable based on requirements *
Content Management Layer	Interfaces between content creation components. Customizable based on requirements *
Custom AR plugins	Allow creation of AR content based on available or newly developed 3D contents, including video and audio. Plugins available for Autodesk 3ds Max, Maya, Trimble SketchUp, Nemetschek Vectorworks, Scia Engineer, Maxon Cinema4D, and can be customized for other software and needs.
Web based Content Creation tools	Allow definition of additional content online like, for instance, location information and additional multimedia contents
Administration Backend	Platform and services: login, authentication, security, etc.

	RDBMS and server side code
Web Server**	Manages http/https communication with DBMS and the mobile and admin clients
DBMS**	Database Server, Relational DBMS
Solution Layer	Interfaces and Communication services that link the backend, frontend and content creation tools. Depends on the specific solution*

* These components are typically customized based on requirements specifications
** Infrastructure components

Table 1. Software components and technology

4 A generic Use Case for Maintenance

Company WXY manufactures an industrial product M (e.g. a machine). The machine M is composed of several components that enable a series of processes, e.g. p1, p2, p3 .... pn. When the machine requires maintenance, replacement, repair of parts, the Smart Maintenance solution allows to:

1) build a database of information about the different components (or machines) and the content relevant to the maintenance processes
2) for each machine or component, create a variable set of maintenance tasks (that can be modified and that may correspond to the enabled processes p1, ... pn), wherein each task contains several maintenance steps
3) create different user profiles with different privileges and enable a specific user to access one or more specific tasks
4) ensure that operators, connected via their mobile device (mobile phone, ipad, tablet, etc..) to the corporate network, access the updated content of the assigned maintenance tasks remotely
5) once in front of the machine to be repaired, operators are supported during operation with real-time information that improve the operator's ability to perform a task in an efficient and effective way; the most advanced way to access information is provided by the use of Augmented Reality that super-imposes, onto the camera image, the contextual information necessary for the operator to quickly and accurately accomplish the task; finally, operations, or the data collected on site, can be communicated to the enterprise backend (for example, to access information about the availability of components)
6) all the information is available and accessible online by the operators and managers, who can track the status of the execution of tasks by the maintenance workers

7) The same system can be used to support training, by creating specific training programs, according to a "situated learning" paradigm.

In this context, the definition of the data structures of the maintenance scenarios is relatively simple, and can be done through simple web-based interfaces, by any person entitled to perform such a duty.

On the other hand, the autonomous creation of contents requires the ability of the companies to create and prepare the 3D assets required for maintenance (possibly by relying on a third party service or on the internal engineering department). To this aim, assuming that the company already has the 3D models, the solution provides several tools to make them available for Augmented Reality. The AR content management system allows to achieve this goal in a completely autonomous way.

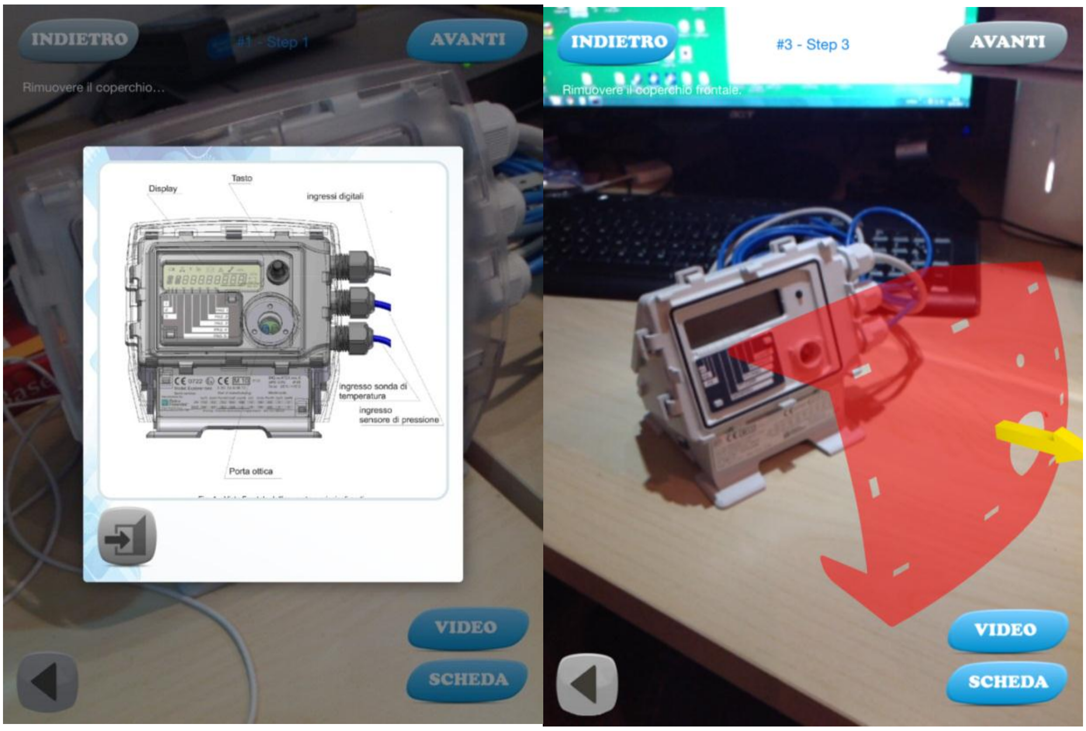

Figure 6. AR application for the maintenance of a "gas metering" device.

5 Benefits and Estimation of the ROI

Why is it good to adopt a solution of the type described above? An answer can be found in the available information about the benefits that such a solution can bring to the company.

In such contexts, it is estimated that an AR solution for maintenance on the field can improve efficiency and reduce costs around 20%-30%. By estimating the average time employed by the operators in the old fashioned maintenance of machines, it is possible to infer the saving that the AR technology allows to obtain.

Another benefit is related to the potential reduction of human error, which also has associated costs.

A further benefit is related instead to the improvement of security that results from the efficient implementation of best practices.

Most of the benefits intervene in scope with OPEX savings, in some cases, up to 15% per annum.

6 Suggested Approach and Roadmap

The goal of implementing the Smart Maintenance solution presented in this whitepaper is two-fold. On the one hand, it allows to make better use of information already available in the company in relation to the maintenance of the assets; on the other hand, it exploits the potential of Augmented Reality technology for improving the performance in training and operations, so as to achieve levels of effectiveness and efficiency never experienced before.

The use of Augmented Reality to support the operations and training of the operators involved in the maintenance of complex industrial machinery, with the primary purpose of improving the performance, also provides significant savings in the number of workers, execution time and cost.

If mobile technology has not already been used in the company, to take the first steps with mobile applications and Augmented Reality in industrial settings will definitely require a structured strategy. The introduction of Augmented Reality in an industrial context, in fact, is a very different process from the use of the same technology in other areas, such as marketing.

As is the case of the adoption of a Mobile Strategy, the adoption of an Augmented Reality Enterprise Strategy requires a careful and thorough analysis of the goals and requirements as well as the solutions that allow to achieve them.

Despite the limited information that you may initially have on the requirements of a project, in general it is possible to define a three-step approach that takes the form of the Roadmap represented in Figure 7.

It's worth noting that the duration of each phase is variable and that, furthermore, there is also a stage 4 (as the phase 3, not commented for brevity) corresponding to the industrialization of the use of AR for maintenance in the way it was briefly described in this document. Stage 4 is relevant in the scenario of formalization that starts from the level of the departments or units, through the rollout of the divisional, corporate, group up to including the most relevant partners. It's also important to note that the proposed Roadmap is just an example and is offered here as a baseline exercise because developing a roadmap can be useful to better define the tactical activities, projects and quick wins, to support an effective deployment strategy for AR applications in business.

Phase 1 - Plan and Organize (2-8 months)

- **Goal**: to demonstrate the potential of AR technology in a suitable application scenario relevant to the mobile learning strategy of the company; to get an understanding of technology implementation comprendere le caratteristiche dell'implementazione della tecnologia, help structuring business and training requirements; identify needed assets and setup AR development capability to support future initiatives
- **What**: test AR technology and its effectiveness, using a reference application in real training /operations that could be deployed on Apple App Store Google Play. No private application store and no integration with enterprise backend is required
- **How**: ask Inglobe Technologies to build and/or support the first implementation of an AR intiative for maintenance, with guaranteed success of the initiative

Phase 2 - Architect and Deploy (3-18 months)

- **Goal**: extend AR capability to all applicable and relevant training initiatives; enable complex scenarios through integration with the enterprise backend; research server side MADP middleware technologies supporting industrialization of AR initiatives
- **What**: first AR project(s) are on-going; implement a solution that comprises both frontend and backend. The frontend may include a Web-based Admin client, a Mobile client, Content creation tools. The backend may include the server communication services and a database.
- **How**: buy in for AR in training and operations obtained; keep focus and complete current projects; first integration with the backend completed; ask Inglobe Technologies to build or support the more complex implementations or projects, with guaranteed success for the initiative ; implement Inglobe's tools to support agile content creation and deployment on the field

Phase 3 - Industrialized AR (9-24 months)

Figure 7. Example of three-phase approach supporting introduction of AR at the enterprise level.

For more information, please contact:

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