Novel Tools and Approaches for Remote Maintenance Activities

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Abstract

Manufacturing today can be geographically scattered and reconfigurable. The augmenting use of commissioning and subcontracting is a growing sector. More and more customization of products and processes is required. In this competitive environment, the maintenance process can become one of the key parameters for the operational success.

The adoption of novel technologies (that includes industrial IoT, Virtual and Augmented reality-AR, Decision Support Systems-DSS for analysis and recommendations, combined with wearable technologies and localization modules as well as thermal and depth cameras for accident prevention and detection) integrated in a new kind of environment, is helping factories to obtain better quality with less costs. This is especially true in the context of those market niches that are becoming more and more strategic for the European manufacturing industries, characterized by high quality, rapidly changing of products and high embedded value.

1. Introduction

Remote maintenance can play a vital role for batch, reconfigurable and continuous process production lines. Especially in continuous processes the downtime of the plant is of essence among other parameters to be optimised, as well as the time for response of the maintenance team and actions for fault diagnosis. Furthermore an intelligent Decision Support System can provide targeted real-time information for addressing the work order, thus facilitating the task (schematics, specification of equipment and analytics, historical data for similar faults, maintenance procedures etc.). It is evident that remote maintenance tools save time and cost because they allow for an experienced maintenance technician to supervise the performed activities and guide the team wherever the shop-floor level might be in real-time. The main outcome of the remote maintenance tools in continuous process systems is to take advantage of the existing information and knowledge and turn them into actionable knowledge for each member of the technical team [Feiner et al. 1993].

Companies where new technologies are applied with the objective in particular of improving maintenance processes belong to very different sectors and include medium and large enterprises, ranging from automation, car manufacturing, batteries construction, medical and vaccines, bio-energy and biomass plants, ceramics machinery construction and logistic). In particular, a high impact is evident in the control of the final products and in preventive (condition based) and corrective maintenance of the machinery used for the industrial production.

Business and productivity enhancers are more and more considering the possibilities of the wearable devices. According with Forrester Research’ reports, the potential market for wearable computing solutions in enterprise settings might actually eclipse that of consumer. The list includes various devices, such as: sensors, cameras, localization modules, glasses for the Augmented Reality (AR). In particular, the AR is widely considered as one of the most important technology for the human interactions; it is based on the concept that digital objects, such as 3D models, animations or textual labels, for example, by means of a special device, are integrated into the real-world space as seamlessly as possible, creating the illusion that all the objects (virtual and real) coexist in the same space. Regarding the required hardware for the use of such technology, AR Glasses can be roughly divided in two categories: AR glasses and AR helmets. Moreover, driven by the advances of hardware and software, Mobile devices (like phones, tablet etc.) are also emerging as interfaces for supporting AR interaction.
2. Human-centric approach

One of the key issues related to the use of wearable technologies is the Human Factor. There are many research studies investigating the impact of these technologies in the workers’ life. Cognitive aspects, related to AR interaction, are also deeply investigated. Most of the studies converge on the conclusion that, in order to develop effective applications, a better understanding of the impact of the AR on human activities is necessary [Dünser et al. 2007].

The crucial point is that the excessive mental workload, potentially related to the interaction with complex interfaces, has the propensity to result in mental fatigue, which can have the undesirable effects of increasing the frequency of errors and/or decreasing the efficiency. The NASA task load index is an interesting example designed to quantify mental fatigue [Hart and Staveland, 1988]. From our surveys, it emerges that one important factor of uncertainty for managers and decision makers is the acceptance from workers and the internal organizations (Unions). On the other hand, expectations in term of cost reduction and better productivity are quite clear. The costs and the implications related with the introductions of wearable devices are instead still vague. This regards in particular aspects like privacy, safety, factors of stress, request of an excessive effort for the workers and so on. Also the compliance with existing laws and established rules in safety and ergonomic of working sites, is a well-considered issue. These uncertainties can be a real barrier, even a blocking factor, to the introduction of these emerging technologies. The best approach to overcome these problems, seems to be step-by-step experimental approach, with clear objectives, totally shared with workers [Tang et al. 2003].

2.1 Safety and Ergonomics

In order to achieve a full transformation of factories into attractive workplaces, designing factories as places that provide pleasant working experience, it is necessary to take into consideration also the aspects related to the interaction between workers and machines (safety and ergonomics). Ergonomics, according to International Ergonomics Association, is "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance". We usually refer to ergonomics meaning all actions taken to guarantee a satisfactory working condition under general constraints of health and safety regulations.

European Community directives on safety at work and their national implementations have given a new and deeper impulse to the study of working places more and more satisfying for the workers. We can say that the directives have given a very strong impulse to develop harmonized standards and draft standards on the issues of ergonomics. The main reference standard is ISO/DIS 9241-11: 2015, but other ISO and EN standards as well. The comfort in work environment is now gaining increasing importance under the pressure of the market, and there is therefore a higher attention of the European legislation for this issue. However, it must be noted that the quantity and breadth of these standards are not even remotely comparable with standards developed in other fields, such as that of the machine safety.

The social policy of European Community states, but also from other continents (North America), is now increasingly appreciating the benefits deriving from a new approach towards working conditions as an important enabling factor to enhance overall profitability. Very often, however, a traditional approach tends to consider ergonomics as an additional cost for machinery and equipment, neglecting thus the crucial aspect that comfortable workplaces bring many and important benefits to the factory productivity (from economic as well as from social point of view).

Anyway, at least in the first implementation phases, additional expenses and investments are undeniably needed to ensure a safe and comfortable working environment.

Companies operating in a mass production paradigm must know the level of performance of the worker and strive to improve working efficiency: this is especially true where the employee are delegated tasks more and more complex, due to the greater flexibility of man if compared with machines (even automatic). If we consider a typical automotive scenario, in usual practice assembly lines composed by a large number of manual stations show significant advantages in terms of production flexibility improvements, but there is a typical drawback in terms of production efficiency of the system when the cycle time of manual stations becomes very low. This may be very well highlighted through a virtual discrete event simulation. The reason of production worsening lies in the fact that workers employed in a specific manual workstations cannot keep the cycle theoretically assigned to them during the shift, if this cycle has not been previously calculated and thoroughly determined with the scientific and technical tools developed
by ergonomic science. This is a first proof that ergonomics compliance costs may be highly compensated for by related productive benefits. Moreover, the calculation of the cycle time for manual or semiautomatic workstations is not possible without careful ergonomic analysis, which will have to verify the correctness of the cycle time calculated by the formal tools of Work Analysis. A theoretically safe machine, which is not also ergonomic, will not be really safe, as it will inherently lead to non-safe behaviour by the human operator. The contrary is not true, since ergonomics takes formally into account all aspects of human-machine interaction, and thus the safety requirements as well. Thus, an ergonomic machine will be also safe by definition.

![Figure 1: Trunk bending from forward to backward. It is recommended to strive for working postures with an upright trunk.](image)

**Picture 1** Examples table for workers right posture

The development of computer technology and their application to industrial environments implied a significant increase of IT supporting media usage. New tools and devices simplified from one side the working activities, but from the other introduced new constraints in the area of health, safety and ergonomy. In particular the introduction of this new technology in an already existing working environment requires a specific attention for the contemporary usage of traditional workplaces and IT devices. These aspects have been examined in the Directive 90/270/CEE that reports all the norms for the control of devices and personnel in charge of using video terminals, and the minimum requirements to be satisfied during their usage. With specific focus to augmented reality devices, such as AR Glasses, actually there is no specific norm regulating their usage, further effort is required in order to establish the parameters for their application in industrial environment and developing specific regulations.

### 3. Real-time data

As discussed, in continuous process systems the downtime of the plant is very important. A critical component for the optimum implementation of maintenance procedures is the usage of the real-time data as acquired by the automation systems that monitors each process system. The challenge is to acquire, integrate and analyse these data from an ever increasing range of operational sources without creating solutions that would increase the work effort for the maintenance team and to be able to engage technicians that are not necessarily located at the shop-floor.

#### 3.1 Organization of the real-time data to an asset-based framework

Process data are related to equipment and from that a knowledge based approach can be derived in order to organize the real-time data from the I/O (Input/Output) field into an asset-based framework. Therefore, instead of handling isolated data, the focus is towards the asset that contains the sensor which produces the real-time data. The information from the assets enable the involved actors to define asset-specific condition indicators either from sensor data or through data calculations. Condition indicators are also related to the asset data and can be used to initiate maintenance tasks based on real time conditions. The real-time asset data come from the on-line monitoring automation system (temperatures, pressures, start/stop of pumps, etc.) or portable test equipment (calibration equipment for status of the thermocouples, electrical tests, etc. Hence, there is a structured description of equipment and the technician focuses on the problem without consuming too much time to relate the process indications to assets, as this is already archived by the asset-based approach. The real-time asset data provide visibility into the asset condition and maintenance schedules can be planned. The use of remote maintenance tools could play an important role in improving corrective, planned or condition-based maintenance strategies that are applied at the shop floor.

#### 3.2 Utilization of real-time data for remote maintenance tools

The remote maintenance tools in conjunction with the framework of data-driven planning and online events notification are applied to prioritize asset management decisions according to shop-floor needs and their status. The implementation of remote maintenance tools includes the integration of the work orders and it ties together real time data with work management systems in an iterative and evolutionary process. The usage of such tools at the shop-floor are bound with specific objectives such as: i) Reduction of the maintenance cost (as off-site personnel can be
involved), ii) Improvement of asset reliability (as at the end the appropriate expert has supervised the activities and ensures that the assets are functional), iii) Improvement of asset availability (as experts can be called upon demand to assist novice or unexperienced to specific malfunctions technicians and thus minimize asset downtime).

The enhancement of maintenance activities at daily shop-floor events with remote assistance could provide various benefits to the involved technicians. Furthermore, these benefits are extended to the decision making actors of the shop floor. As far as the technicians are concerned the integration of real-time data using the asset-based approach to the remote maintenance tools can provide: a) Visibility to the status of the SCADA, PLCs and other systems, in an organized way, on one mobile device or PC, b) Instantly check the status of an asset, without having to explore through multiple screens, c) Take the right action on critical alarms, d) Be able to move around the shop floor and be notified upon demand for contributing to an incident, e) Monitor real-time KPIs and maintenance instructions, based on your proximity to equipment, f) Remotely respond to data alerts and alarms for faster and easier troubleshooting and assist the onsite technicians.

Overall the remote maintenance tools empower with real-time data increase the collaboration among the team members and provide appropriate resources such as schematics or sharing of information via HMLs. Furthermore one of the most valuable features is the access to instructions regardless of the location where the technician might be.

4. Wearable technology and Augmented Reality

There are many possible applications of AR in the industry, ranging from support in manufacturing processes up to maintenance of products and systems. It has been proved that assembly applications can benefit substantially from the improved memorization attainable via AR which can shorten the training time of new employees [Ke et al. 2005]. Enhancement of long-term memory is also a strong positive factor in the understanding and retention of assembly or repair sequences, procedures and other information. Nevertheless, despite the advances of the technology, many critical issues are still open. This is mainly due to the complexity of the AR systems. That includes the hardware technology and the software algorithms. Another big issue is related to the, sometime under-evaluated, Human Factor aspects. As far as technology is concerned, one of the most widely reported challenges, related to the efficiency and the power of the software algorithms, is the accurate object tracking. In fact, if an AR system misrepresents the location of a virtual object relative to an accompanying physical object by even a very small margin, the visual mismatch between the physical and virtual objects is very easily noticed by the human eye and can be source of mistakes. Some further challenges depend more directly on the particular type of the AR application. For example, it can be difficult to sense the state of the physical objects in the working area. This would apply, for instance, when attempting to allow an AR system to detect the degree to which an assembly has been completed at any given moment [Welch and Foxlin 2002].

From the point of view of the Human Computer Interaction (HCI), AR creates a totally new paradigm, far from the classical concepts of graphical interfaces and Graphical User Interfaces (GUIs). The typical conceptualizations of classic GUI were adequate in the past but, with today's AR technology, many more interaction techniques are possible [Feiner et al. 1993]. AR applications can utilize a wide variety of elements in order to facilitate information flow between the system and the user. This means that the interaction is intrinsically complex. That can result, potentially, in a factor of distraction. This is a crucial point were researchers, software developers and hardware engineer are working intensively. The research regards the three main aspects of the AR application: information presentation, physical interaction and shared experience [Azuma 1997], Gabbar (2001), has assembled a list of basic guidelines for interface design within VR and AR applications, based on 46 references, covering subjects ranging from AR-specific research to general interface design theory.

On the other hand, AR, in combination with localization technologies and interconnection to integrated control and diagnostics systems as well as CMMS systems already deployed in industries can provide a more direct way to present context-aware notifications to workers, maintainers and managers alike regarding monitoring of production lines and equipment, including equipment malfunctions, production errors, hazards and accidental incidents. In this regard, AR can provide overlaid data that is localized to the exact position of the incident, offer first-person views into potential solutions in connection to a DSS system as well as guide through maintenance and repair actions in a user-centric way that no other human-computer interface can provide. Gavish et
al., 2015 have shown in their evaluation of virtual reality and augmented reality training for industrial maintenance and assembly tasks that overall, AR training for industrial maintenance and assembly tasks can reduce the number of unsolved errors, and thus their potential undesired consequences.

5. Decision Support System

A DSS may access and assess information from diverse sources (multi-sensorial system, automation system, IoT, alarms at shop floor level, CMMS, production planning, BoM, BMS etc.). Its objective is to offer suggestions on how to prioritize and take actions. Moreover, it offers or redirects the involved stakeholders to all the data required to make an informed decision as well as the tools to perform the tasks associated to them. In the remote maintenance activities, there is considerable added value to the usage of a DSS, because it can save time and resources. The avoidance of information availability shortage alone is a considerable advantage to pursue. Previous recommendations and their results can be used as training data in order to assess the effectiveness of the provided recommendations, suitability and applicability of the DSS. Selecting relevant KPIs to monitor and improve is also part of the continuous development of such systems. It goes without saying that high data protection and security is crucial using Asymmetric Cryptography and other standards.

5.1 Decision makers’ view

It is humanly impossible to process the magnitude of data accumulated by the industrial manufacturing processes in the smart (or not so smart) factories. Even in the more traditional operating enterprises, when there are multiple operating sites and maintenance teams need to coordinate actions, there is a need to handle a large amount of information coming from multiple sources. Multiple events happen real time date are being transmitted and fast and efficient decisions need to be taken. If you add the remote distance factor, the stakes are much higher. Decision makers and supervisors need to receive suggestions on how to organize their processes, prioritize actions and issue work orders. Already existing and accepted solutions by the maintenance community offer work scheduling capabilities. The next step is to automate and optimize this procedure, by offering suggestions that leverage some of the burden from the supervisors’ shoulders. The priority assignment to pending work orders needs to account for preventive maintenance schedules, corrective maintenance issues, as well as availability of equipment from the production operation. In the novel approach, the DSS will suggest automatically a prioritization order for actions to be taken. The key is to continuously reassess this order, so that use of resources is maximized and that backlog pending tasks are considered too. Data processing by the DSS will enable proposals for selection of workers who are suitable, skilled, competent and available to take over a task. Categorizing and grouping the available resources needs to be also coupled with data on proximity and urgency. The system will facilitate the work planning, as well as the work scheduling.

5.2 Workers’ view

The workers involved in carrying out remote maintenance are phasing multiple challenges. Missing tools, guidelines, spare parts, skilled personnel etc. can result to considerable delays, mistakes and added stress. Hence, the necessity for a decision support system is evident. Workers/Operators need to receive timely guidelines, the necessary tools, information on their work scheduling and to be informed on the management expectations. Using online available checklists and other verification tools allows for timely information sharing with co-workers and supervisors. The DSS can be also used to retrieve information on how an issue was previously handled, to capitalize on the lessons learned from previous experiences and to avoid mishandlings.

An important factor rising interest in occupational safety and health and one of the most challenging issues is the psychosocial risks and work-related stress. The impact on the health of individuals, organizations and national economies is significant. Workers have the best understanding of the problems in their workplace and their daily activities. It is necessary to ensure safe and healthy working conditions throughout the whole working life and this is feasible by involving them in the decision making process assessment. The evaluation of the DSS by the workers is the key for the acceptance and actual use of such tools, as well as for their improvement.

6. Conclusions

Many practical experiences demonstrate that the adoption of the wearable computers can be helpful in modern warehouses. Expectations are growing more and more. Regarding in particular the Augmented Reality, the opinion of some analysts is that it is still a relatively immature
technology, at least if compared with the Virtual Reality, and a great deal of progress needs to be made on a number of fronts before it will have wide scale appeal. It is a fact that Virtual Reality has a solid technological basis that works, and it is already making significant commercial inroads, AR is still in an experimental stage for most of the early user adopters.

Our experience demonstrates, instead, that, even if the benefits promised by the AR will not be realized automatically and an investment is always necessary for the introduction of such new technologies, in the other hand, benefits exist in the medium-long term with valuable results in terms of error reduction, productivity increase and more comfortable working conditions.

Real experiences also demonstrate that the adoption of AR technology for remote assisted maintenance can have positive effects not only in the reduction of direct and indirect costs and in a better integration with the value chain, but also acting as potential factor of business, as far as the possibility of selling Added Value Services during the after-market of the products, is considered.

In conclusion, far from been another technological buzzword, the wearable computers will be in the next few years, a concrete reality and, maybe, a necessity for any company operating in the modern competitive markets.

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