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A TESTING PROCEDURE OF A DIGITAL APPLICATION FOR SAFETY IMPROVEMENT IN A BEVERAGE PLANT

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ABSTRACT
Safety at the workplace is one of the most relevant issues for companies, due to the high number of accidents happening every year, some of which even deadly. Despite that, this number is decreasing thanks to continuous research and to an increasing application of safety procedures and devices. In line with that, the project presented in this work intends to develop and evaluate a new solution to improve operators' safety, at a reasonable cost (including adoption and use). The usage of wearable systems (smart-glasses and smart-watches) will improve the efficacy of the solutions previously tested on mobile devices like tablets and smartphones. Although no new devices were developed, the project required the creation of a new software tool, in which a great amount of information was inserted to allow its correct functioning.
The main aim of this work is to create a testing procedure to evaluate the impact of this solutions on the employee's safety. This is extremely important to demonstrate the efficacy of new industry 4.0 applications.

Keywords: Augmented Reality, work safety, Mixed Reality; case study, Industry 4.0.

1. INTRODUCTION
One of the last polls made in the EU28 (EUROSTAT 2018) shows that in 2015 there were more than 3 million of accidents (causing more than four days of absence from work) with almost 4 thousands deaths. These numbers only refer to Europe, which is considered as a reference zone due to the high level of technology and attention paid to safety and, also, where advanced solutions (such as that described in this study) can be easily applied. Nevertheless, there is no doubt that safety concerns are global problems, having a greater impact on the third-world and the developing economies, where culture and laws do not consider workers' conditions. Globally, about 340 millions of accidents and 160 millions of work-related illness are observed every year, with 2.3 million of deaths (International Labour Organization 2008).

Conventional solutions aiming at increasing safety are not always able to completely remove risks, mainly due to the implicit nature of works itself, and also to the operators' behaviour or their level of training (Leão and Costa 2019). There are also further aspects to be taken in account: has the system been designed with a high level of security? (Kolbachev and Salnikova 2019). The level of safety was adequate time ago; is it safe enough now? (Song and Yang 2019).
With the purpose of enhancing the operators' safety, a research project, W-Artemys (Wearable augmented reality for employee safety in manufacturing systems), was started by some Italian institutions and aimed at introducing the new technologies offered by the well-known fourth industrial revolution in the safety context. More precisely, the aim of the project is to propose new solutions based on Augmented Reality (AR) which can help workers while performing their tasks directly on the machinery; the support of AR is expected to help reduce errors and accidents. This is particularly the case for complicated procedures, where employees are likely to make mistakes or to forget steps, thus causing machine downtime and, consequently, unplanned production standstill.
AR was selected among the Industry 4.0 technologies for its characteristic of being *smart*: indeed, it can be easily installed on handy or wearable tools, such as tablets, smartphones or smart glasses; the use of these devices is immediate and understandable, and their cost is quite affordable (Bottani and Vignali 2019). Whether (or not) the implementation of AR is appropriate in the specific context under examination can be assessed thanks to a framework developed by Rosi et al. (Rosi, Vignali and Bottani 2018) and further developed by Bottani et al. (Vignali, et al. 2019).
On the basis of the premise above, the aim of this paper is to discuss the implementation challenges for a AR application intended to improve the safety level at the workplace and to detail a procedure for testing the effectiveness of the tool developed. As such, this study can be useful to guide similar implementations of AR for safety improvement in industrial contexts.

The remainder of the paper is organized as follows. Section 2 provides an overview of the W-Artemys research project, in which this study has been carried out. Section 3 details the testing procedure for the AR solutions. Section 4 describes the expected benefits as well as the possible issues arising from the implementation of the tool. Section 5 concludes and indicates future research activities.

2. THE W-ARTEMYS PROJECT

2.1. Overview

The W-Artemys project is multi-disciplinary in nature, as it required different knowledge and competences in various engineering fields; this is why the project required the collaboration of different universities. With the financial support of INAIL (Italian insurance institute for work-related accidents), the University of Parma (UNIPR), University of Genova (UNIGE) and University of Calabria (UNICAL) started the development of W-Artemys platform. This platform collects mainly three different systems, i.e.: a database, a vocal assistant and an augmented reality tool. The software has been designed to be implemented on commercial devices (tablets, smartphones or smart glasses), thus avoiding the need to develop an *ad hoc* physical support. The timetable of the project was based on two years of activity, but an extension of further six months have been requested and approved by INAIL.
Table 1 shows the activity planning, including the tasks completed and those currently in progress.

Table 1: Work plan for the development of the W-Artemys system

	2017				2018				2019			
Main software development												
Database compilation												
Vocal assistant												
Alarms management												
Augmented reality implementation												
Testing phase												

The W-Artemys platform has a modular architecture: based on the main software (which manages the database information), the vocal assistant, the alarms management system and the augmented reality system are added as plug-in. The plug-in system was chosen to allow the project partners to work independently on the W-Artemys platform, even if the system itself was not completed. This logic is used for most of the minor options included in the project, like the QR code generator and reader, the search tool or the pictures and pdf upload module. The QR code generator can be used to create QR codes to be placed in specific parts of the machine; when read by the device's camera, the code directly links to the related argument or document. The search tool allows to use specific keywords to find elements, avoiding a manual screening of the W-Artemys' database. During his activity, the operator can also upload useful documentation, such as pictures or pdf files. All these elements have been designed to help the employee in his activity, to perform his tasks avoiding errors, thus increasing the safety level without jeopardising his efficiency (operation time).
In the last months were also added specific systems to manage the alarms of the set of equipment and to use the AR to help the operators during one specific activity, which was selected due to its complexity (bottles size changeover).

2.2. Software structure

As can be seen in Table 1, the first months of the project were spent for the development of the main software architecture, i.e. the basic program where all the remaining elements will be installed. This work was mainly done by UNICAL. Once the structure of the software tool was sketched, pieces of information about the machines to be tested were collected in order to fill the database. Two companies, both based in Parma, were involved in the application of the tool and will collaborate to the testing phase: GEA Procomac (GEA – engineering for a better world s.d.) and Parmalat (Parmalat 2019). GEA Procomac is a market leader in the filling machines field and is the manufacturer of the machine selected for the application of the W-Artemys tool; Parmalat is one of the main beverage companies around the world and is the user of the selected machine. An aseptic filling monoblock, manufactured by GEA Procomac and located at the Parmalat site, was chosen as case study. A detailed description about the machines themselves has been presented in a previous work (Vignali, et al. 2019); for completeness, a short description will be reported also in section 2.3.
Once the W-Artemys architecture was sketched, UNIPR started filling the database by entering information about the selected machine. This activity required to convert the information collected in a format compatible with the software structure; more precisely, information entered and files uploaded had to be clear and easy to read and to understand by the user. It was also necessary to create a precise logic to organize all the files inside W-Artemys platform; this activity was carried out in a previous work (Vignali, et al. 2019).
The first step to create the database was to examine all the machines' manuals in order to extrapolate the relevant information and determine how to organize it. To comply with the tree structure of W-Artemys and create a user-friendly interface, operations were grouped into different sets, with intuitive names.
Overall, the amount of information retrieved was organized in around 200 groups and files. For any new element created there is the need to fill in many information (such as description, keywords, reference picture, reference colour) and to upload the relevant files.
The vocal assistant was activated at the beginning of 2019. The function of this plug-in is to allows rapid search and to retrieve the relevant groups of elements as results, or directly answer the questions raised by the user. For the system to function, it is necessary to insert a set of keywords for every block. The choice of the

keywords is crucial for the correct functioning of the system: indeed, only if inserting specific keywords, the system is able to retrieve the required item as answer. In line with this principle, several possible keywords were inserted in every research field, including synonyms, so as to allow the operators to use different words and obtain the answer they are looking for. With respect to the answers themselves, they need to be created for each single question, in every element, in such a way that the vocal assistant is able to give back the information searched.

The last months were focused on the implementation of the alarms management system, which is the last element required before implementing the AR tool. The general structure of the alarm management system was discussed together with all the project partners. Implementing this plug-in requires the W-Artemys software to be real-time connected with the machine's database; this is actually one of the main obstacles for this module. Indeed, nowadays companies are increasingly concerned about cyber-attacks, and also, old machines are not predisposed to be connected to the internet. When an internet connection is available, firewalls are typically installed and only few and trusted connections are allowed. To allow the alarms management system to work, information on the state of the aseptic filling monoblock should be exchange *via* web. This kind of information exchange is mandatory due to the different physical location of the W-Artemys server and the machine server: the first one is located in the UNICAL's servers and the second one is at the company's site. After dedicated meetings, the project partners came to the conclusion that a read-only access to the alarms database could be provided and that a mirroring server should be implemented. This compromise solution allows the W-Artemys tool to identify the active alarms and send notifications to the operators. To this end, two main tasks have been carried out:

- First, has been created a table linking each alarm code to the corresponding restoring procedure (in W-Artemys). This should allow UNICAL to link the alarm of the monoblock to the right solving procedure;
- Second, as far as the software is concerned, has been implemented the alarms plug-in.

Although the table linking alarms and solution procedures has a quite simple structure, its creation was not so immediate; indeed, machines such as those considered in this study contain hundreds of sensors and, consequently, generates hundreds of different alarms or warning. Thanks to the guidance of GEA Procomac, all the alarms generated by the monoblock were collected: their final number totals more than nine hundred alarms and warnings. From an analysis of the resulting list, three main points were noticed:

- Not all the alarms turned out to be relevant for the purpose of this study, as they are not included in the machines' manuals; their code has been therefore skipped in the table;
- Some operations correspond to more alarms codes generated by the machine;
- Some alarms codes have no description, which makes it difficult to understand their object.

A preliminary screening of the alarms was made by looking at the first sixty rows of the alarm table generated by the monoblock. This screening was intended to quickly create some data to be inserted in the alarms management system for testing purpose. The choice to create a list of a subset of alarms was motivated by the following considerations:

- The ongoing development of the alarms management system involves uncertainty about the logics behind them. Hence, a pre-test phase of the alarm management tool should be carried out with a subset of alarms, to try its functioning;
- Related to the previous point, because of the high number of alarms, the full list of them will be more effectively handed when the alarm management module will have been debugged.

Based on this issue, the alarms management module has been created and it was able to collect from MSql server 2008 R2 only the selected alarms and to display them on the mobile devices (Tablets and smartphones), where the W-Artemys have been installed. Nowadays the notifications of the alarms appear out of the app (but in the same devices) and then the operators should find the solution inside the W-Artemys app. A test will be done also using smartwatches as wearable devices, able to receive the alarms, while other devices like tablets or smartwatches will help to solve the problem on the set of equipment.

Finally, the AR app has been realizing both on the wearable devices (smart-glasses) and on simple mobile devices (tablets and smartphones). This application is made in order to help the operators, which actually work on the equipment, to do also difficult activities such as the bottle size changeover (now it is performed by specialized maintenance operators). The AR application needs in this case the usage of tags in order to understands the exact position with the aim to add digital information on the real images. This functionality is implementing in both the wearable and mobile devices, with the differences that in wearable solutions the act to skip or validate the phases is different from that of mobile systems (tablets and smartphones need only to press a key).

Section 3 will describe a first series of tests that will be carried out on the whole system. Nonetheless, some specific tests on the different plug-ins of the W-Artemys tool also need to be carried out, to check their performance singularly. This standalone and internal test has been already done with the W-Artemys modules developed up to now. This procedure allowed to check every aspect of every module in detail, so as to arrive at the final test with all components working properly.

2.3. Tested machine description

As mentioned earlier, the machine chosen for the implementation of the W-Artemys tool is an aseptic filling monoblock. Despite its name, the monoblock consists of five machines. Following the production flow, once the bottles enter the monoblock, they are processed by the sterilizing machine, whose main aim is to sterilize the bottles, inside and outside, in such a way to destruct the bacterial count without interacting with the plastic. Hot peracetic acid is used to this end.
At the exit of the sterilizing machine the bottles require a washing process to remove the residue of peracetic acid. The washing machine is similar to the previous one in its structure, but instead of a cleaning fluid, sterilized water circulates inside it.
Once washed, the bottles enter the filling machine. A critical process is made here: the sterilized product from the production plant is injected inside the bottle, and the environment must be as clean as possible to avoid any contamination of the product.
Once filled, the bottles reach the capping machine. Caps, previously sterilized in a machine similar to the steriliser, are screwed with a precise torque on bottles. This last operation ends the process, which is summarized in Figure 2.

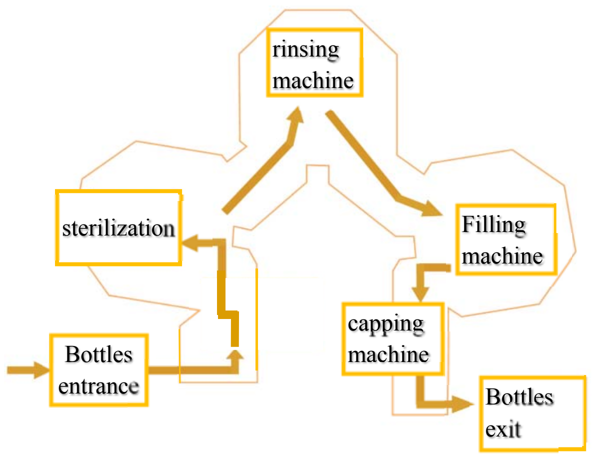

Figure 2: Production flow of the aseptic filling line.

Almost all the processes take places in an aseptic environment; in this regard, when the bottles exit from the sterilizing process, the air inside the machine has to be purified too. To this end, a series of ventilators with air filters are installed on the machine. This system allows to keep the pressure inside the monoblock higher than the ambient pressure, meaning that no particles will enter the machine and contaminate the product or bottles. These strict conditions of cleanliness are guaranteed by the manufacturer for a limited amount of time only; every one hundred hours, it is necessary to perform a Clean-in-Place (CIP) and a Sterilising-in-Place (SIP) process in order to restore the initial conditions.

A more detailed description of the monoblock can be found in (Rosi, Vignali and Bottani 2018) and (Vignali, et al. 2019).

3. TESTING PROCEDURE

According to some preliminary analyses carried out with Parmalat, the format changeover on the whole line was chosen as operation to be converted in AR and, consequently, tested. Indeed, the bottling line in question deals with four different bottle formats and the procedure, performed when the five machines are switched off, generates a significant downtime.

Tests will be performed by UNIPR and are planned between November and December 2019. This timing is due to the seasonality of products manufactured by Parmalat (which occupies the plant full time from April to October) and to the availability of the W-Artemys system, which is expected to be complete in September 2019.

Four employees from Parmalat, preferably inexpert, will be involved in the testing phase. They will be introduced to the project and then trained on the devices they will have to deal with. Other four employees from Gea Procomac will be selected in order to understand the differences among these and those of Parmalat.

Between the total forty-three activities to be carried out during the format changeover, by removing the redundant ones (i.e. those that are repeated several times), the following eleven resulted:

1. Adjusting the height of the inlet conveyor;
2. Disk rotation;
3. Guide pin and guide regulation;
4. Bottles stop pads replacing and regulation;
5. Replacement of the entrance scroll;
6. Guide adjustment;
7. Starwheel replacement;
8. Guide replacement;
9. Dowel replacement;
10. First sector of the guide rotation;
11. Second sector of the guide rotation.

Some of these will be selected based on the following criteria: ease of investigation from the external part of the equipment, repetitiveness of operation on the various machines, utility of the technological solution for the specific operation. Indicatively the duration of the operations must not exceed 15-20 minutes for practical reasons.

The aim of the tests will be to evaluate the effectiveness of the AR solution during the execution of the abovementioned activities. To do this, each task will be repeated four times by the four operators of GEA

Procomac and Parmalat with the support of four different tools:

a. Printed manual;

b. Tablet and wearable device (without AR implementation);

c. Tablet and wearable device (with AR implementation);

d. Voice assistant.

Tests are planned so that for some phases of format changeover operated by a single person, all the four tools will be used by the same person; in this way, results can be more objective and not affected by the specific user experience (e.g., with AR devices or vocal assistant).

Each repetition will be timed through a manual digital chronometer and supervised.

As far as the key performance indicators, we will consider as quantitative outputs the time spent for completing the operations and the number of errors made by the users during the execution of the tasks. Once observations will be recorded, statistical analysis can be considered. As we deal with a test carried out for one factor (the AR) at four different levels (the four tools), an F-test can be performed, i.e. the analysis of variance (ANOVA). Design Expert release 7.1 software package (Stat-Ease, Inc., Minneapolis, USA) will support this data processing.

Finally, through a survey we intend to present in retrospect to the operators involved, we will also acquire qualitative feedbacks on the users' response, e.g. on the ease of usage or perception of safety. To this end we plan to use the unified theory of acceptance and use of technology (UTAUT), which is a technology acceptance model formulated by Venkatesh et al. (Venkatesh, et al. 2013) on the basis of a review of the existing theory acceptance models. The UTAUT model aims to explain user intentions to use an information system and subsequent usage behaviour. The model takes into account four core determinants of intention and usage (i.e. 1) performance expectancy, 2) effort expectancy, 3) social influence, and 4) facilitating conditions), and up to four moderators of key relations.

4. CONCLUSIONS AND IMPLEMENTATION CHALLENGES

One of the main challenges identified in the whole project is the creation of a well compiled database. Indeed, information on the operations to be converted in AR are often not sufficiently detailed in the machines' manuals. As mentioned before not only operations are troublesome to be collected but also all the information that must be included inside the W-Artemys. In general, from a practical perspective the development of this kind of solution needs a huge amount of manual work, which could be even greater if the application is to be replicated on different machines.

Again from a practical point of view, a further difficulty encountered was to link the alarms codes with the corresponding description in the manuals. Indeed, the internal database contains all the alarms generated by the machine, but these alarms are often redundant or unclear in their name; this makes it difficult to directly link them to the correct restoring procedure. A company technician (in our case a GEA Procomac manager) was involved in this phase to explain the meaning of the machine alarms.

From a systems' perspective, an alarms management system, as the one designed in W-Artemys, requires (at least now) an internet connection, in order to read the alarms status of the machine. This requires the possibility for the machine to put and share information online, and the company's availability to allow this information exchange.
Based on these peculiarities, in conclusion, the activities performed have shown how it is complex to implement industry 4.0 solutions on an existing machine due to in particular the use of updated version of software and the need of high performances of informatics hardware. All these activities could be easily done on a new machine where all the systems could be based on the same operating system.

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