FEASIBILITY STUDY OF AN AUGMENTED REALITY APPLICATION TO ENHANCE THE OPERATORS' SAFETY IN THE USAGE OF A FRUIT EXTRACTOR

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ABSTRACT

This paper proposes a framework to carry out a feasibility study of the implementation of augmented reality (AR) systems in the manufacturing context, to enhance the safety of employees in carrying out maintenance tasks. AR systems are recognized as effective tools to help a user perform tasks and operations, by adding virtual information (such as live-video stream, pictures, or instructions) to the real-world environment. A feasibility study and its application to a real context has been carried on in collaboration with a primary manufacturer of food equipment. The targeted machine is a hot-break juice extractor, manufactured by the company; the machine is used to separate juice from fruit pieces The operation where the AR systems is intended to be applied is a maintenance task, concerning the cleaning or substitution of the porous sieves of the machine. Such a task should be carried out at least every 12 hours of functioning of the machine. The main steps for the development of the AR solution, as well as the expected pros/cons of its implementation and usage are discussed.

Keywords: augmented reality (AR); feasibility study; employee safety; maintenance; food machinery.

1. INTRODUCTION

Traditional risk assessment techniques, used to evaluate workplace safety and security, showed in the past some limits in reducing the frequency and severity of accidents at work. This is mainly due to the unpredictability of human behavior that, in some circumstances, could lead to non-compliance of rules related to the workplace safety. In fact, it has been estimated that over the 65% of work accidents is caused by human errors (Geller, 2001).

On the basis of these considerations, behavioral based methodologies for risk assessment have been employed in some cases; however, they have not reached a wide industrial application, due to the lack of specific competences inside the company (Wirth and Sigurdsson, 2008), the need for the support of computer-based systems and the high cost (Zhang and Fang, 2013).

A current challenge is to find a standardized method that is able to monitor industrial activities and to reduce the number of accidents, especially due to the man-machine interface. To this end, employees could be helped, during the execution of risky tasks (such as maintenance tasks), by augmented reality (AR) systems or by voice assistance systems. AR encompasses a set of technologies through which the view of the real world environment is augmented by computer-generated elements or objects. In other words, the term AR refers to a mediated reality, where sensory perception (in particular, visual perception) of the physical real-world environment is enhanced by means of computing devices. AR aims at simplifying the user's life by bringing virtual information not only to his/her immediate surroundings, but also to any indirect view of the real-world environment, such as live-video stream (Carmigniani et al., 2010).

Based on these premises, a feasibility study is proposed in this paper to evaluate the profitability of implementing an AR system to help the operator in the execution of some maintenance tasks on an automatic machinery, which is part of a fruit juice processing plant. The AR application is intended to be installed on a mobile system, such as a smartphone or a tablet. The operator will capture the scene of interest with the device camera and will receive the same scene on the display; the scene captured will be augmented with information, warning and videos, which could help the employee to carry out the maintenance tasks in a correct and safe way.

The remainder of the paper is organized as follows. Section 2 provides the reference framework that can be followed for the feasibility study of AR implementation in real contexts. Section 3 details the feasibility study along with its application to a real industrial case. Section 4 discusses the main findings of the study and indicates future research steps.

2. REFERENCE FRAMEWORK

As mentioned, the targeted case study refers to the analysis of a maintenance task, which is carried out on a food machine that is part of a fruit processing line.

The machine under examination is a hot-break juice extractor, which is used to separate juice from fruit pieces. Hot-break means that the product entering the machine has been heated up to 85÷90°C. There are four main components of this machine, namely: a stator, a rotor and two cylindrical sieves.

The rotor is concentric to the stator and rotates inside it. The external surface of the rotor contains some paddles, which force the fruit pieces against the sieves. Being pressed by the paddles, the fruit releases its juice, which can pass through the sieves, while the peels, the seeds and the fruit pieces are held back. The size of the holes diameter on the sieves depends on the product that has to be processed, although it is usually in the range 0.2÷2 mm. Moreover, the paddles located on the external surface of the rotor have a specific inclination, which allows to push the fruit residues towards the machine end section, where they are discharged, so partially avoiding the clogging of the stator. The targeted machine can process up to 100 ton/h of product. Figure 1 shows a 3D modeling of the main machine components.

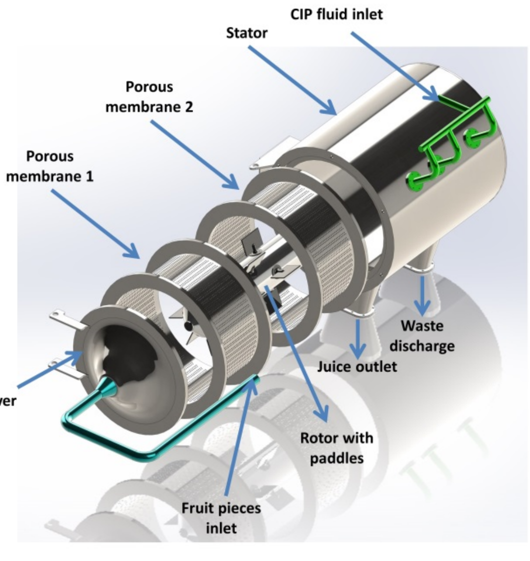

Figure 1: Main components of the juice extractor.

From Figure 1 it can be noticed that the stator is closed with a cover, through which the product to be processed is inserted, and that a pipeline located on a side of the stator carries inside its chamber some sterile water, that can be used for a gross Cleaning In Place (CIP) process.

The operation targeted to evaluate the implementation of AR systems is a maintenance task, concerning the cleaning or substitution of the sieves of the machine. This operation consists, roughly, in the following actions: (1) stopping the machine; (2) removing the two sieves; (3) cleaning them with a water jet; (4) re-position the sieves inside the stator correctly; (5) starting again the machine. If the sieves are severely damaged or if a product change has to be carried out, the two sieves will not be cleaned; rather, they will be replaced with new ones, as the holes dimension depends on the product that has to be processed. In this case, the operator should also pick the new sieves from the warehouse and make sure that they are suitable for the type of production that will be realized once the machine is re-started.

According to the plant manufacturer, if the production line is working at full capacity, the operation described is quite frequent, being required at least every 12 hours. Changing the sieves ensures that the line efficiency is kept constant and, at the same time, should avoid an excessive wear of the paddles and of the sieves themselves, due to an accumulation of fruit residues in the stator chamber.

This operation was chosen among the whole set of maintenance tasks that can be carried out on the targeted equipment because it is relatively frequent and also because it exhibits a not negligible risk level. Indeed, before the execution of the described task, the machine is working and has to be cooled; consequently, the operator is likely to come into contact with very hot product (up to 85÷95°C) and with moving parts. The manufacturer evaluated and managed these risks selecting technical and procedural measures described in the following section.

To evaluate the implementation of an AR system to help the employee in the execution of the targeted task, the following steps must be carried out:

1. collecting all the necessary data about the machine and task. Examples of these data include technical drawings of the machine or at least of the relevant components, or the detailed description of the procedure targeted for implementation (for instance, retrieved from the machine operating and maintenance manual);
2. collecting other useful information, such as photos of the equipment or of part of it, photos of the tools required to carry out the targeted operation, etc. Videos of the operation carried out by a skilled worked could also be useful to reproduce the correct execution of the task;
3. organizing the acquired information and data by means of tags or similar categorization tools. Such a classification is expected to make it easier for the AR system to search and display the proper information, for instance in response to an employee query;
4. developing the AR application. This step reflects the software implementation of the AR solution, embodying all the data collected before;
5. analyzing (or estimating) the expected cost and benefits.

In the continuation of the paper, we will address almost all the above points, along with their implementation in the targeted context. The only exception is step 4, i.e. the development of the AR application, since it deserves to be described in full detail and thus will be object of a further work.

3. FEASIBILITY STUDY

We now detail the steps briefly described at the end of the previous section.

3.1. Step 1: Analysis of the procedure for sieves cleaning/substitution

A summary of the steps to be followed to carry out the targeted maintenance task, according to the maintenance and operating manual of the juice extractor, has been proposed in section 2. It is, nonetheless, useful to depict them in the form of a diagram, as proposed in Figure 2, since such representation help identify the sequence of activities as well as their logical relationships.

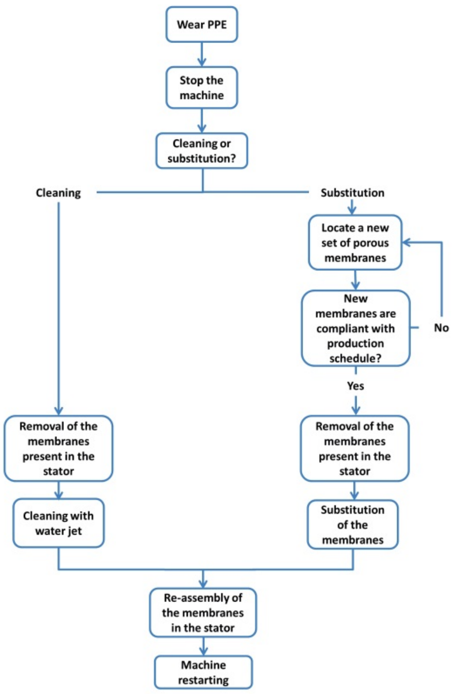

Figure 2: Main steps for the sieves cleaning/substitution.

As can be seen from Figure 2, the first activity the employee should carry out consists in wearing the required Personal Protective Equipment (PPE). In this case, we recall that the main risk is to come into contact with hot products; accordingly, the required PPE are protective and heat resistant gloves, compliant with EN 407, and a protective screen.

The second step of the task is to stop the machine. In order to do this, the following actions have to be carried out:

- from the electric panel of the machine, turn off the product flow by acting on button 13 (see Figure 3);
- close the manual ball valve located on the product supply pipeline (B);
- close the manual valve located on the juice outlet section (C);
- open the drain valve (D);
- open the manual butterfly two valves on the water supply pipeline (A), so to pre-wash the stator chamber;
- from the electrical panel, stop the machine by pushing button 11;

  turn the main switch (6) to position “0”. This switch is an interlocking device with guard locking. This is a supplementary safe measure that ensures the reachability of the stator when its hazardous movements are stopped. Selection and installation of this safety device have moreover to minimize the possibility of defeating in reasonably foreseeable manner (see requirements contained in the standard EN ISO 14119:2013).Figure 3 and Figure 4 show the main components of the electrical panel and of the machine on which the operator must act to properly carry out the operations previously described.

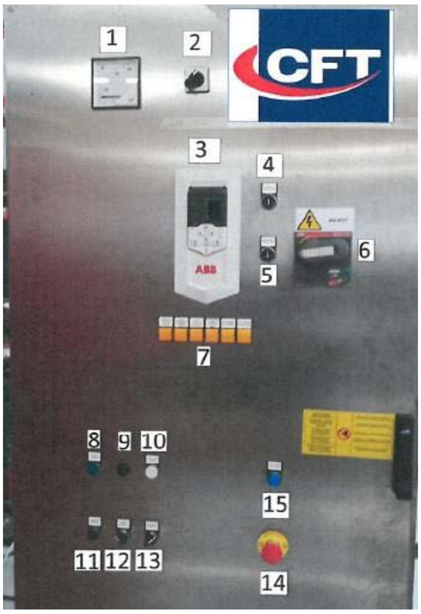

Figure 3: Machine electrical panel.

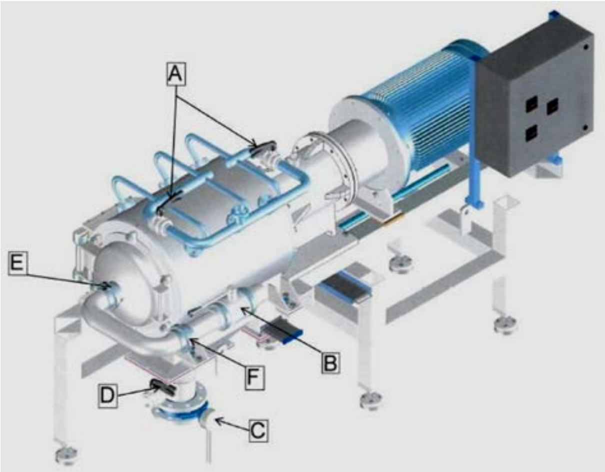

Figure 4: Machine representation.

The components listed in Figures 3 and 4 are detailed in Table 1.

Table 1: Description of the components listed in Figures 3 and 4.

Electrical panel		Machine representation	
No.	**Description**	**No.**	**Description**
1	Voltmeter	A	Water supply butterfly valve
2	Voltmetric switch	B	Product supply ball valve
3	Keyboard	C	Juice outlet valve
4	Increase rotor rotation speed	D	Drain valve
5	Decrease rotor rotation speed	E	Coupling between product pipe and stator chamber
6	Main switch	F	Coupling in product supply pipe
7	Anomalies indicator		
8	Machine start		
9	Cork		
10	Product feed indication		
11	Machine stop		
12	Local control/remote control switch		
13	Enabling product feed		
14	Emergency stop		

Once the machine is stopped, the operator has to choose whether to carry out a simple cleaning of the porous sieves or their full replacement. In this latter case, he/she has to pick the new pair of sieves and check if they are compliant with the kind of product scheduled to be processed after the machine restarts.

At this point, the employee should remove the sieves located in the stator chamber. The actions required to properly perform this operation are the following:

- unscrew the coupling E (see Figure 4 and Table 1);
- loosen the coupling F (see Figure 4 and Table 1), so as to remove the product pipeline from the machine's cover;
- unscrew the cover locking nuts using a 30 mm wrench;
- open the machine's cover;
- screw the supplied pullers on the first sieve and remove it;
- repeat the last action on the second sieve.

Once the above set of tasks has been completed, the sieves can be cleaned or, if damaged, replaced with the new ones. Finally, the sieve has to be re-assembled and the machine has to be restarted. It is self-evident that, to assemble the sieves and restart the machine, it is sufficient to follow backwards the actions listed above.

3.2. Step 2: Data collection

After the description and the analysis of the procedure retrieved from the maintenance and operating manual, we carried out a detailed data collection phase. This step is intended to gather all the relevant information that could be useful to develop the AR application. Examples of relevant pieces of information are technical drawings, photos of the whole machine or of some parts, and/or photos of the tools required to carry out the set of activities described in the previous sub-section. Videos reproducing the behavior of a trained operator, who is carrying out the sieves substitution, have also been recorded. To this extent, some visits at the company's site were carried out from May to July 2016.

Examples of information retrieved during site visits (e.g., pictures of some small particular features of the machine, tools used to lock the machine's cover) are proposed below.

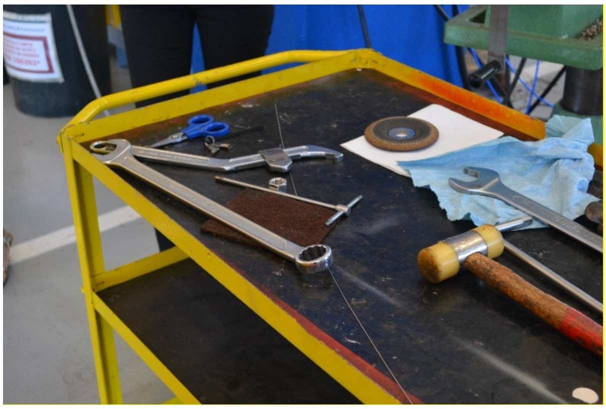

Figure 5: example of tools used during the targeted maintenance task.

Figure 6: the sieves to be substituted during the targeted maintenance task.

Photos and pictures are also useful to set up a feature-based tracking of the machine and its main parts. This means that machine and components can be recognised directly based on their shapes or other characteristics features, avoiding the use of markers (marker-less systems). Otherwise, AR systems typically make use of markers to identify either machines, equipment or safety devices. In the case in exam, however, these markers would need to be placed on the machine or on elements/parts of machine, which, however, could compromise its functioning. For instance, a marker could not be placed on the sieve, to recognise it, as the sieve is in direct contact with the food product. Moreover, the fruit is at hot temperature, meaning that the marker would be subject to relevant thermal excursions.

3.3. Step 3: Organization of the acquired information

In many cases, AR systems couple the 3D rendering of the machine being reproduced with a set of video or print instructions and a personal (voice) assistant. In the case under examination, all the above elements are planned to be included in the AR solution that will be developed for the targeted machine.

The design of the personal assistant, in particular, requires a further preliminary step, i.e. the classification of the information acquired by means of keywords or questions that the employee could ask when carrying out the task supported by the AR system. Indeed, personal assistants work by using a natural language user interface to answer questions, make recommendations, or perform actions, while retrieving the relevant information from a set of keywords.

There are several ways to organise data so that they can be used by a personal assistant. The simplest way is to identify the possible questions a non-expert employee could ask when carrying out the task of cleaning/replacing the sieves of the extractor. As an example, let's think about the first task of the list in section 3.1, i.e. "from the electric panel of the machine, turn off the product flow by acting on button 13". A non-expert employee could ask, for instance, the following questions:

1. Where is button 13? What is button 13 for?
2. Where is the electric panel?
3. What is the correct movement for turning off the product flow?
4. …

Obviously, the set of questions listed above is not exhaustive and is intended to provide only an example of possible indications a non-expert employees could ask when carrying out the first task of the targeted procedure. Nonetheless, some keywords can be easily identified from this set of sample questions, for instance "button 13", "electric panel", or "movement". Categorizing the data collected means giving them a sort of tag ("button 13", "electric panel", "movement"), so that the personal assistant is able to search the answer to the employee questions by screening the tags. To be more precise, anytime an employee asks, for instance, "where is button 13?", the personal assistant will identify the keyword "button 13" and will return the whole set of data which have been tagged with "button 13".

3.4. Step 4: Development of AR application

The next step is the development of the AR solution, including the 3D rendering of the machine being reproduced, the augmented information (print or video instructions) and the personal assistant. This task reflects software implementation and verification (or debugging). The AR solution can then be installed directly on the machine or used on a personal digital assistant (PDA), for instance for remote training of new employees.

The real development of the AR solution is a complex step and, actually, is not the focus of the present work. More precisely, for the targeted application the AR solution is being developed by other partners of the SISOM project (specifically, from the University of Calabria and University of Genoa). Therefore, the related details will be described in a separate work.

3.5. Step 5: Cost and benefit estimate

The last step of the framework consists in estimating the cost and benefit resulting from the use of the AR system in the targeted context. At the time of writing, as mentioned, the AR solution is still being developed, which prevents the possibility of providing a quantitative evaluation of the cost and benefit resulting from its application in the real scenario. Nonetheless, some indications about the potential cost and saving resulting from the use of an AR solution to support the task examined can be provided.

With respect to the cost of AR, the main components obviously include the cost for data collection (step 2), for the organization of the pieces of information to make them usable by the personal assistant (step 3) and the cost for developing the AR solution (step 4). In addition, the AR solution needs to be either installed on the machine or tested though laboratory experiments. These costs are quite easy to be estimated, as most of them consist in manpower costs.

With respect to the expected benefits, it is worth mentioning that some authors in the literature have discussed (and sometimes also quantified) the benefits resulting from the use of AR systems in real cases. Among others, these benefits can include:

- Faster execution of the task by the employees (Sääski et al., 2008, Serván et al., 2012);
- Faster training of the employees on maintenance tasks (Besbes et al., 2012: Webel et al., 2013);
- Lower number of errors made by the employees when carrying out the task (Webel et al., 2013);
- Higher accuracy in assembly tasks (Rios et al., 2013);
- Decrease in the number of accidents or near misses related to the task supported by the AR system.

The above elements should be quantitative evaluated in the specific context to assess the suitability of adopting the AR solution.

4. DISCUSSION AND CONCLUSIONS

The possibility of using AR system to support the execution of maintenance tasks has been widely explored in many sectors of manufacturing industry, as shown by the published literature. For instance Webel et al. (2013) have shown that AR systems could be helpful in the assembly and maintenances of machines used in the beverage sector. De Crescenzio et al. (2011) instead, presented a prototype, based on an AR system, to help operators in executing maintenance tasks on aircrafts. Other cases are reported for instance by Sääski et al., (2008) (agricultural machinery industry) and by Salonen et al. (2009) (automotive industry).

In most of the cases the adoption of an AR system was appreciated by the operators and it brought many benefits such as, for instance, faster execution of the tasks, lower number of errors and a decrease in the time required for a proper training of inexperienced operators (see section 3.5).

The same benefits are expected in this case too. However, as at the time of writing the implementation of the AR system has not been tested (yet), the capability of the solution developed to decrease the risks associated to the targeted task still has to be evaluated.

Obviously, to assess the convenience of adopting this kind of application, the benefits mentioned above should be quantified through experimental tests and related to the cost expected for the system implementation. In general we can expect that this latter cost consists of five main components, i.e.:

1. cost for data collection;
2. cost for the organization of the pieces of information to make them usable during the development of the application;
3. cost for purchasing the hardware required to develop and implement the application;
4. cost for developing the AR solution;
5. cost for implementation and testing.

If we exclude the cost components 1 and 2, which are expected to have a limited impact on the total cost of the system (because they are representative of the operations that require less manpower to be carried out), the remaining cost components will be carefully estimated and then monitored during the application development.

Finally, a prototype will be built and tested, so that the cost/benefit ratio could be evaluated. In the case of favorable results, the natural next step will be the implementation of the system in the real industrial environment.

REFERENCES

Besbes, B., Collette, S. N., Tamaazousti, M., Bourgeois, S., Gay-Bellile, V., 2012. An interactive augmented reality system: a prototype for industrial maintenance training applications. In Mixed and Augmented Reality (ISMAR), 2012 IEEE International Symposium on (pp. 269-270). IEEE.

Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., & Ivkovic, M., 2011. Augmented reality technologies, systems and applications. Multimedia Tools and Applications, 51(1), 341–377.

De Crescenzio, F., Fantini, M., Persiani, F., Di Stefano, L., Azzari, P., Salti, S., 2011. Augmented reality for aircraft maintenance training and operations support. IEEE Computer Graphics and Applications, 31(1), 96-101.

Geller, E.S., 2001. Behavior-based safety in industry: realizing the large-scale potential of psychology to promote human welfare. Applied & Preventive Psychology, 10, 87-105.

Rios, H., González, E., Rodriguez, C., Siller, H. R., Contero, M., 2013. A Mobile Solution to Enhance Training and Execution of Troubleshooting Techniques of the Engine Air Bleed System on Boeing 737. Procedia Computer Science, 25, 161-170.

Sääski, J., Salonen, T., Liinasuo, M., Pakkanen, J., Vanhatalo, M., Riitahuhta, A., 2008. Augmented reality efficiency in manufacturing industry: a case study. In DS 50: Proceedings of NordDesign 2008 Conference, Tallinn, Estonia, 21.-23.08. 2008.

Salonen, T., Sääski, J., Woodward, C., Korkalo, O., Marstio, I., Rainio, K., 2009. Data pipeline from CAD to AR based assembly instructions. In

ASME-AFM 2009 World Conference on Innovative Virtual Reality (pp. 165-168). American Society of Mechanical Engineers.
Servan, J., Mas, F., Menéndez, J. L., Ríos, J., 2012. Assembly work instruction deployment using augmented reality. In Key Engineering Materials (Vol. 502, pp. 25-30). Trans Tech Publications.
Webel, S., Bockholt, U., Engelke, T., Gavish, N., Olbrich, M., Preusche, C., 2013. An augmented reality training platform for assembly and maintenance skills. Robotics and Autonomous Systems, 61(4), 398-403.
Wirth, O., Sigurdsson, S.O., 2008. When workplace safety depends on behavior change: Topics for behavioural safety research. Journal of Safety Research, 39, 589–598.
Zhang, M., Fang, D., 2013. A continuous behavior-based safety strategy for persistent safety improvement in construction industry. Automation in Construction 34, 101–107

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