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Assembly Operations Aided by Augmented Reality: An Endeavour toward a Comparative Analysis

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Abstract

Costly complex assembly operations supported by augmented reality demands endeavors to achieve a comparative and experimental depiction of different circumstances for assays to analyze fluctuating conclusions where the situation with limited number of tries has compelled to recognize that variations exist depending on test conditions. Then developments in emergent technologies, for training in Maintenance and Repair Operations (MRO), must be evaluated. Scenarios are focused on assessing an AR request, by stating a confrontation of declarations about assembly time and comparisons respect to outstanding authors who conduct assembly operations. An assembly operations case study establishes a small sample size during experimentation.

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Keywords: augmented reality (AR), complex assembly, experimental conditions, maintenance, aeronautical assembly, small sample.

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1. Introduction

The industrial context involving complex assembly operations requires time-consuming and expensive training methods. Significant advances in various technologies provide opportunities to reduce cost and increase efficiency of such training methods for complex assembly. One of these new technologies is Augmented Reality (AR), which provides a combination of virtual with real images, without substitution of the real environment, in real-time interactive fashion. Although researchers have written much about AR applications to enhance assembly operations, an analysis of related work reveals several areas of opportunity in regards to a common basis for comparison. Then further research is required to establish a more robust framework for the assessment of AR technologies.

While formerly in a proceedings paper by Suárez-Warden et al. [1], an assay about an assembly kit was exhibited to try to obtain the sample size by arranged phases to reach an acceptable amount to execute the costly trial, now in order to make analysis, a test of hypotheses is used as a support tool for assessing the experiment. Although at first it is prudent to utilize a well-selected sample size for making a satisfactory contrast of training by mean of AR versus traditional technique (TT), after that, it is judicious to discuss a comparison to outstanding authors.

Tests associated to complex assembly are often expensive and provide a small amount of data. This research deploys a comparative assessment of AR assisted assembly and provides some insight into its potential advantages by focusing on assembly operations of intricate components. A case study is utilized involving complex and time consuming activities, including more than 3 hours of concentrated work. A nomenclature is exhibited as follows.

Nomenclature

μ	Population mean
μ_o	Population mean difference ($\mu_1 - \mu_2 = \mu_{TT} - \mu_{AR}$) assigned to the null hypothesis
S	Sample standard deviation (measure of variability of an assumed representative set of data)
$\hat{s}$	Sample standard deviation estimation
$\hat{s}_D$	Combined sample standard deviation estimation [min]: standard deviation of the sample mean
σ	Population standard deviation
$\mathbf{t}cr$	Critical value for t distribution (threshold for null hypothesis acceptance or rejection)
$t\alpha,\nu$	t distribution as a function of α and β
ν	Degrees of freedom (df)
α	Level of significance (probability of Type I error)
β	Power of test related value (probability of Type II error)

On the other hand, motivated by an earlier work presented in The Communications and Transportation Systems workshop (CTS) of ICTON 2011 conference by Suárez-Warden et al. [2], we agree with the opinion that suggests must exist an evaluation from an experimental setup approach including productivity or performance components (like the thorough assembly times) so that it can be possible to provide strong evidences about a higher training efficiency that may be reached by AR aided assembly which a priori is taken for granted as a better technique for assembling but until now only due to its intangible benefits.

1.1. Related work

Azuma [3] and Azuma et al. [4] illustrate the pioneering work associated to AR. Neumann and Majoros (from Boeing) [5] have addressed the cognitive issues associated to AR in the manufacturing and maintenance environment. Raghavan et al. [6], cited by Pang et al. [7], established an interactive evaluation of assembly sequences, which AR-based assembly evaluation tool would allow a manufacturing engineer to interrelate with the assembly planner while manipulating the real and virtual prototype components. Their sensing technique uses computer vision along with a system of markers for automatically monitoring the assemblage state as the user manipulates assembly components. They propose to improve a robotic assembly sequence planning by advancing visualization aids, and in particular, an AR tool for assembly sequence planning and on-site assessment. This AR interface allows mixing of real and virtual prototype components to increase quality of assembly sequence valuation, where human intuition/experience is brought out by pooled manipulation of real and virtual elements.

Reinhart and Patron [8] describe capabilities and advantages of a modular Augmented Reality system for guiding manual assembly integrating their method for AR into the planning process of the workstation. An early work of Wiedenmaier et al. [9] showed the potential of AR during an assembly of a car door and indicated that AR assisted assembly provided advantages only for tangled operations.

Wang and Dunston [10] analyze the feasibility of augmenting human abilities via mixed reality that offers in construction from a cognitive engineering angle and generate guidelines to solve ergonomic problems. In their experiment, they detect that perceptual incompatibility by using the monitor versus head mounted display (HMD) is significant regarding orientation time, accuracy and workload. Pang et al. [7] propose an assembly feature design in an AR environment that supports the top-down design approach to provide proper assembly constraints via model-based collision detection, in the early project stage. Their prototype system allows user to generate new assembly parts by a union Boolean operation. They showed the benefits of AR supporting the design for assembly.

Ong et al. [11] developed a platform for planning and evaluation of assembly operations based on worker stress for different sequences of assembly. The assembly sequence with less stress has been used as reference for further refinement of the early product design. Yuan et al. [12] tested an AR aided assembly system that included a virtual interaction panel and a visual assembly tree structure where research was conducted with 14 volunteers who assembled a toy train and a computer.

Caarls et al. [13] describe the design of an optical see-through head-mounted display system and its quantitative and qualitative evaluation which can be used for AR for art design applications; they affirmed that accurate measuring of head motions is crucial and made a head-pose tracker for the HMD that uses error-state Kalman filters to fuse data from an inertia tracker with data from a camera that tracks visual markers, what makes on-line head-pose based rendering of dynamic virtual content possible.

Henderson and Feiner [14,15] explored benefits of AR documentation for maintenance and repair by undertaking design, execution and user testing of a prototype AR application on The U.S. Marine Corps (USMC) mechanics operating inside an armored vehicle turret. Their prototype used a tracked head-worn display (HWD) to augment a mechanic´s natural view with text, labels, arrows and animated sequences designed to ease task comprehension and performance. Some findings were that the AR condition allowed them to locate tasks more quickly than when using improved version of currently employed methods and, in some instances, resulted in less overall head movement.

Sorensen [16] argue that for a nuclear power plant, maintenance plans which are communicated through blueprints, 3D digital models and written descriptions, all incorporate the need for high efforts of abstraction and interpretation, and are thus both difficult to understand and easy to lead to misinterpretations. So, a simulation with full scale 3D models experienced in the physical setting where operations are to take place would previously bring operators closer to the real life assignments and AR is a visualization technology providing this design advancement.

According to De Crescenzio et al. [17], AR offers a great potential in diminishing training costs involved in assembly and MRO, as well as reducing procedural errors during operations. Nee et al. [18] review the investigation of AR uses in design and manufacturing exploring seven main related sections, including industrial progresses.

It may be perceived, in many works, that while benefits exist in assembly and maintenance aided by AR, previous research only has offered a few specific examples of AR aided complex assembly. There are technical advances in registration and tracking, increase of tolerance to occlusion and illumination changes, assembly feature design, AR-based assembly sequence evaluation, mixed prototyping use and others. Conversely, although the mentioned authors have gotten notable progresses in quality for assembly, design and maintenance, we have suspected that most of them have not taken into account the assembly time (or the training minutes for assembling) to measure the (assembly) process performance through the work times, concern that has a direct impact in the availability of assembled equipment, i.e., airplanes when the case is assisted MRO, being this a primary worry in aviation industry.

In Section 2 a case study is presented including its experimental description. Results, discussion and analysis are in Section 3 and conclusions and future work in Section 4.

2. Case Study

Due to aircraft systems complexity and safety concerns, the aeronautical industry works under strict regulations, requiring a large work force of highly trained personnel; assembly operations, existing in MRO, are regulated by The FAA or Federal Aviation Administration, [19]. And as a result of its intricate nature, aeronautical maintenance is an intentional area for applications assisted by evolving technologies to reach high efficiency improvements.

The complexity associated with aircraft systems and the elaborate procedures required in MRO operations provide a context where AR technology can increase performance by declining training and assembly times and growing effectiveness; for this reason there is a priority necessity to analyze involved aeronautical experiments where the operations of the assay constitute a critical matter. And there is a contradiction because while high quality is demanded to aeronautical technicians at the same time they are claimed for reducing their training and assembly times, therefore it is decisive to develop a particular interest in the issues of productivity and performance. So, it is pertinent to deliberate about the value of the quantity of time invested in training programs and their economic benefits when an enterprise (or project) uses AR in order to compare its return to the required mandatory standard rate or minimum attractive rate of return (MAAR).

2.1 Experimental Case Study Description

Six trials are performed and they are to be described. There is one factor evaluated, it is the method used to transfer the knowledge. The different configurations available for this factor are TT, MMDG (multimedia design guide) and AR methods, therefore these are the levels. Thus the process has one factor with 3 levels however only 2 levels were evaluated in this case. The outputs of the process measured were assembly time, errors and questions. These 3 outputs are the 3 quantifiable parameters. Summarizing, the experiment has 1 factor (method of knowledge transference), 2 levels (TT and AR) and 3 outputs: time, errors and questions; which are measured to cover cognitive (informational related) and psychomotor (work piece related) aspects. Elements for undertaking the assay are: laptop, tracking software, marker, camera and tripod. In this monitor-based system, an AR station is made up of an Acer Aspire 3680 computer (Intel Celeron M processor, 1.5 MB DDR2 RAM memory and Intel Graphics media accelerator 950) to display assembly instructions. The camera is a Micro Innovation Basic Camera (model: IC50C). Test parts are intended for training in assembly operations needed for the RV-10 aircraft. The kit with 12 aluminum parts (Fig. 1) was integrated with all the pieces and rivets.

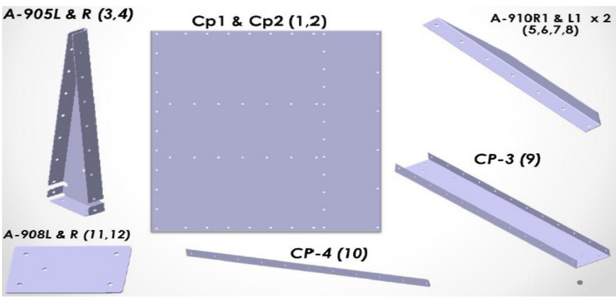

Figure 1. Parts of assembly kit of the RV-10 aircraft.

The tools needed to correctly execute the assembly are the following: rivet gun, hand driller, rivet cutter, priming machine, C-clamps, metal cutting snips and deburring tool. The markers are black and white design to be recognized by the software used to form an application which is written in C-lite language and runs under a Gamestudio A7 compiler. Testing subjects (users) were a total of 7 male engineering students. None of the students had any prior knowledge about assembly, process or tools used for the instruction kit. See Figure 2 with archive photo of research.

Figure 2. Assembly trial by riveting on a wing of RV-10 airplane within Lab.

An introduction for users (who were all appointed individually) is given during the assembly. Once the time starts running they begin with the adaptation process to the instruction interface (this time is in the total time) and direct toward all the steps in the guide. The supervisor is available to user at all times and is allowed to answer questions. Nonetheless, supervisor is an impartial assistant by helping the user in certain operations of the guide because these tasks must be done by two people and details to the user the manual tools, instruction about the kit, the kit's control commands and types of content (text, video, 3D) displayed and focused on transferring of procedural knowledge needed for achieving MRO tasks. Part of the AR practice is adapted and exhibited in Fig. 3. Finally, the supervisor mainly collects assembly times (training times elapsed by AR via) and questions that must be registered during an assembly operation by riveting. Table 2 summarizes the findings.

Figure 3. Display of contents for an AR aided assembly assay

2.2 Scenarios allocated for assembly methods

Diverse scenarios can be generated in order to get estimated values and obtain an average size of work sample. An engineering focused terminology is proposed as follows:

- Experimental characterization: way in which the assay is conducted (showed by a number of features).
- Response variable: that adjustable term through which the outcome is presented.
- Work sample size (n): number of observations to include in a sample, which constitutes an adequate characteristic of any empirical or experimental study; its estimation is n. ˆ

It is pertinent to explore whether the variance of one method (TT) is equal to that of the other (AR) and thus to assume (or to validate) that $\sigma_1 = \sigma_2 = \sigma$ that is $\sigma_{TT} = \sigma_{AR} = \sigma$

Kolmogorov- Smirnov (K-S test) essay is effectuated to validate the goodness of fit (representability) of data to the normal model, considering an empirical model (experimental cumulative distribution function) and the selected model (normal cumulative distribution function). More details about K-S test are provided in The MathWorks, Inc. [20] at www.mathworks.com; since a Gamma distribution also fits, it must make a contrast by testing the Normal versus the Gamma model to decide whether the simplest model (Normal distribution) can replace the more complex parent model. For two models, according to Campbell and Jardine [21], the one with higher p-value is the one that better represents the data. In this case, Normal model has the higher p-value.

Scenarios are exposed in Table 1, adapted from Suárez-Warden et al. [1]. It is based on the formula for estimating the sample size and on the Operation Characteristics Curves (OCC).

Table 1. Scenarios based on formulation or OCC to obtain estimated values of work sample size (n) ˆ

Scenario	Sample type	α	β	Type of shape, variability	Estimated n by formula: n ´
1	independent	.01	-	Balanced, $\hat{s}$ = 32.46	2
2	independent	.01	-	Balanced, $\hat{s}$ = 23.67	3
3	dependent	.01	-	One-sided, $\hat{s}$ = 14.97	2
Scenario	Sample type	α	β	Type of shape, variability	Estimated n by OCC: n ˆ
4	independent	.01	.01	Balanced, $\hat{s}_D$ = 12	8
5 (elected)	independent	.01	.01	Balanced, $\hat{s}_D$ = 10.6	8
6	independent	.01	.01	Balanced, $\hat{s}_D$ = 9.66	5
7	dependent	.01	.01	One-sided, $\hat{s}_D$ = 14.97	11

From this array, a mean sample size is estimated by calculating an average (n_{AV}). When it is not sure that data are associated pairs of dependent samples or independent samples, it is applicable to select a mix of unskewed (balanced) and skewed (one-sided) choices, involving α and β: $n_{AV1} = (8+8+5+11)/4 \approx 8$

Whether data belong to independent samples, thus it must be chosen only unskewed (balanced) selections involving α and β: $n_{AV2} = (n_4 + n_5 + n_6)/3 = (8+8+5)/3 = 7$

As near n_{AV1} and n_{AV2} averages, we consider scenarios 4 and 5 with $\hat{n} = 8$ on table 1 and designate the scenario 5, by regarding a conservative criterion, instead of the scenario 4 to get being traditionalist about variability since $\hat{s}_D$ of 12 (for scenario 4) is higher than 10.6 (for scenario 5). This standard deviation of the sample mean is expressed as:

$$\hat{s}_D = \hat{s} \,/\, n^{1/2} \tag{1}$$

For the balanced scenario 5 of two independent samples: $n_1 = n_2 = n \hat{=} 8$ and $\hat{s}_D = 10.6$

$$df = \nu = n_1 + n_2 - 2 \tag{2}$$

Where df is a combined effect on degrees of freedom: the sum $(n_1 - 1) + (n_2 - 1)$; $df = \nu = 8 + 8 - 2 = 14$ Assuming $\alpha = .01$ (acceptable value in aeronautical sextor), the critical **t** value $\mathbf{t}\alpha,\nu$ becomes:

$$\mathbf{t}cr = \mathbf{t}_{\alpha, n_1+n_2-2} \tag{3}$$

As a result, the t-critical (theoretical amount) of **t** distribution for the designated scenario 5 is:

$\mathbf{t}cr = \mathbf{t}\alpha,\nu = \mathbf{t}_{.01,\, 8+8-2} = \mathbf{t}_{.01,14} = 2.624$ (value that was obtained from standard statistical table).

3. Results, Discussion and Analysis

The first result was *the time it took* the person to complete the assemblage and with this parameter we wanted to establish if AR improved the understanding of assembly by allowing the user to have made it faster. *The errors found* in the assembly included from a misplacement of a part to a bad riveting or alignment, in this case the errors showed whether the assembly was correctly built and if time affected the integrity of the component. The third parameter was *the questions made* by the user that could not be answered with the guide. Conversely Table 2 with outcomes of investigation (depicted below) omits Errors column (which resulted biased) while focus on the time is kept. The modified arrangement is based on data from Rios et al. [22] and Guerra [23] such that for undertaking an allowable filtering process it was removed the farthest point (assay 4 with 5 questions) from the straight line model related to K-S normality test and replaced by the adjusted average ($Xav_2 = 211.4$).

Table 2. Modified results from data of the AR aided assembly and datum of TT method for the tryouts

Assay	X = Assembly time by AR (min)	AR Questions (#)	Revised Assay	AR Questions (#) [Revised]	X_2 = AR time (min)	X_1 = TT time (min)	Difference
1	248	4	1	4	248	No datum	-
2	210	3	2	3	210	No datum	-
3	236	3	3	3	236	No datum	-
4	**284**	**5**	4 (new)	2.6 (average)	211.4	No datum	-
5	197	1	5	1	197	No datum	-
6	166	2	6	2	166	No datum	-
-	–	–	7 (added)	2.6	211.4	N.A.	N.A.
-	–	–	8 (added)	2.6	211.4	N.A.	N.A.
	Original Xaverage	3		2.6	$Xav_2 = 211.4$	$Xav_1 = 243$	31.6 min

Disclaimer: Guerra [23], in his work *Applying Knowledge Management and Using Multimedia for developing Aircraft Equipment*, undertook a related investigation but he did not do a rigorous numerical study, so he only included one datum ($X_1 = 243$ about TT time) taken as an average.

Outcome for AR via is $Xav_2 = 211.4$ as it was removed the farthest point from the straight line model (K-S test) and chosen an average estimated size value $n \hat{=} 8$ by designating the scenario 5 (in Table 1) to execute the next run:

Required data are: α, μo, Xav_1, Xav_2, $\hat{s}$ where: $\mu o = \mu_1 - \mu_2$ using $\mu_1 = \mu_{TT}$ and $\mu_2 = \mu_{AR}$. And by defining:

- Statement for nullifying named Null hypothesis (Ho): premise that the researcher tries to reject (nullify)
- Research hypothesis (H_1): alternative, research or maintained proposition of an investigation

To make the confrontation:

Ho: $\mu_1 = \mu_2$ or $\mu_{TT} = \mu_{AR}$ is established as the premise we must nullify.
H_1: $\mu_1 > \mu_2$ or $\mu_{TT} > \mu_{AR}$ is considered the research proposition we shall try to validate.

That is: Ho: $\mu_1 - \mu_2 = \mu_{TT} - \mu_{AR} = \mu o = 0$ and H_1: $\mu_1 - \mu_2 > 0$ or $\mu_{TT} - \mu_{AR} > 0$

If it is assumed (or validated via **F** Fisher test) that $\sigma_1 = \sigma_2 = \sigma$ and by estimating σ:

$$\hat{s} = [\ [(n_1 - 1)\ S_1^2 + (n_2 - 1)\ S_2^{\ 2}\ ]\ /\ (n_1 + n_2 - 2)\ ]^{1/2} \tag{4}$$

This is called an approximation of σ pooled. From Table 1: $\hat{s}_D = \hat{s}\ /\ n^{1/2} = 10.6$ (variability value associated to the selected scenario 5); now it is pertinent to get the experimental value **t**exp:

$$\mathbf{t}\ \text{exp} = [(\bar{x}_1 - \bar{x}_2) - \mu o]\ /\ \hat{s}\ /(n)^{r/2} \tag{5}$$

$$\mathbf{t}\ \mathrm{exp} = [(\mathrm{Xav}_1 - \mathrm{Xav}_2) - \mu o] \,/\, \hat{\mathbf{s}}_{\mathbf{D}} \quad (6)$$

where $\mu o = 0$ is based on Ho supposition, since $\mu o = \mu_1 - \mu_2 = 0$ by setting $\mu_1 = \mu_2$ at Ho

Calculating: $\mathbf{t}\ \mathrm{exp} = [(243 - 211.4) - 0] \,/\, 10.6 = 2.98$
Versus before found $\mathbf{t}\mathrm{cr} = \mathbf{t}\alpha, \nu = \mathbf{t}\ .01, 14 = 2.624$ where $\alpha = .01$ and $\nu = 8 + 8 - 2 = 14$ since $n_1 = n_2 = 8$

In this case of right end test, experimental and critical values previously achieved are to be compared:
$2.98 > 2.624$ that is: $\mathbf{t}\ \mathrm{exp} > \mathbf{t}\mathrm{cr}$

According to Wackerly et al. [24] it is nullified the statement of equal mean assembly times (during training) for both methods, this is, we must not pass Ho at the elected significance level. So the research premise, mean assembly time by TT is larger than that elapsed by AR technology (H_1: $\mu_{TT} > \mu_{AR}$) is not discarded and hence, it may be recognized the examination of training via AR to be approved. Thus, training efficiency increased by AR aided assembly which can be regarded a better via in this case.

As conditions of development for each experiment are not the same, the derived conclusions are not comparable. The purpose of the test in each study might be different due to different tasks and type of work performed; for three authors the study is evaluative, while two authors aim at a comparative study. There is a clear area of opportunity in regards to standardization of criteria for this type of AR assembly assays. To have comparable results and more reliable conclusions about the impact of AR technology, there is a need to have a reference framework.

Analyzing the items, Task and Cognitive and Psychomotor aspects, which are set to settle at the type of operation to perform and in two of its relevant features, we can see that there are almost all different tasks but possessing the common denominator of their cognitive and psychomotor ability. In almost all the works, interest in productivity and performance exists, approach to be considered to improve the process and included as an in-depth involvement for reflecting the efficiency of assembly operation supported by AR technology.

The AR hardware is diverse, being different in all the cases except in Rios et al. [22] and this proposal that utilize laptop to display scenes, while:

- Henderson and Feiner [15] use LCD versus head-up display (HUD) versus an AR portable wrist display
- Wiedenmaier et al. [9] mention various types of display
- Wang and Dunston [10] use the head mounted device (HMD) versus desktop monitor

The Response Variable, denoting a designated metric, is assembly time which predominates in all cases but with different versions, matter that compels us to worry about to explore how measuring that time is set to undertake a classification leading to locate groups of similar experiments with complex assembly operations aided by AR so we can make the assays comparable. Data collection is effectuated by different ways, some of which use questionnaires before or after assay is performed. A confrontation of premises that is demanded by the formulation of an hypothesis related to a relevant variable, is undertaken by almost all of the authors but the problem is that this is not always explicitly established which occurs in case of Rios et al. [22].

Both data normality test and small sample size determination are important concerns in experimental assembly operations due to the high cost of the samples together with the frequent need to replicate the tests performed, and to the difficulty of making production stops besides the unwillingness of many companies to give their time for rehearsals. There are cases reviewed in which the test is performed but we are worried about that the authors do not present the use of a small sample size as we encourage through our proposal.

A statistical development for the experiments is imminent when we compare each other. As a result:

- Henderson and Feiner [15] use significance level α =0.05 y 0.01
- Rios et al. [22] mention a 95% of confidence level
- Wiedenmaier et al. [9] practice significance level α =0.01 y 0.05
- Wang and Dunston [10] apply significance level α =0.05
- This proposal exclusively uses a significance α =0.01 for severe operations like those in aviation industry and some medical devices sectors.

Most of authors cover a confrontation of premises as a dominant factor of the assay even so some of them assigns a lax significance level, in contrast this proposal, like parts of the work of Wiedenmaier et al. [9] and that of Henderson and Feiner [15], does not agree and allocates a strict level α = 0.01 this is 1% such that may be more acceptable to rigorous industries.

In this work, experimentation is conducted with a training kit for practicing assembly operations of an RV-10 aircraft (four-seat, single-engine, and low-wing). A monitor-based system is used to assist the subject with AR. The mean time for AR assisted assembly is found to be shorter than the time for traditional manual assembly in complex parts, requiring more than 3 hours of continuous work. The study demonstrates a routine for using a small number of experiments in those cases where testing is costly or difficult, while maintaining an acceptable significance.

4. Conclusions and Future Work

Alternative studies of AR aided assembly are analyzed to make an evaluative comparison but then it must be remarked that conditions of each experiment are not the same; the purpose of the assay is distinct in each research along with different tasks, type of job and approach therefore cases are not comparable. A huge interest in productivity must conduct to properly interleave the operations into the augmented reality (AR) programming and be wary about the time invested in training and their economic value when a project (or company) uses AR in order to compare its return on investment (ROI) to the required mandatory standard rate or minimum attractive rate of return (MAAR). Response time is a variable included by all of the seen authors, i.e., a key feature in each assay for doing the correspondent analysis; hence it will be crucial to explore different ways for measuring assembly times in each case. Since it has been detected ambiguity the implication is that maturity does not exists with regard to industrial implementation of AR technology such as Azuma [3] concludes; thus it follows a need to undertake additional experimentation to form a regulatory framework for AR applications to establish a common metric (or equivalency) to designate, for example, adequate significance level, permissible work simple size, normality test requirement and other parameters. This research presents a single case study where some previous experimental data have been exploited to running the assay; although robustness has been expanded by comparing with other studies of varying difficulty, more experimentation is required by mean of additional designated cases that must be thoroughly driven to involve to aeronautical areas and other industrial branches with complex assembly; a classification leading to locate similar pilot groups with complex assembly operations aided by AR technology may be traced. It proceeded to follow a sequence for an experimental assembly example to attest about a diminution in training time by mean of AR aided assembly versus traditional technique (TT); nonetheless a treatment for Errors for avoiding a bias condition requires executing other experiment designed to be capable to reveal the quality of each AR contribution such that the diverse qualities presented by the authors be more comparable. The comparative evaluation, from an experimental characterization perspective includes productivity elements (like the thorough assemblage times) such that be possible to provide evidences that a higher training efficiency can be reached by AR aided assembly which a priori is considered as a better technique for assembling but until now only due to its intangible benefits. The training study intends to demonstrate productivity benefits of AR assisted assembly in aircraft maintenance operations associated to assembly and disassembly of complex systems; this proposed approach is based on an achievement of different scenarios, considering a minimum number of assays that allows for managing a suitable significance level. Procedures must favor the usage of a small sample size during experimentation because of the high cost of each complex assembly assay.

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References

1. Suárez-Warden F, Cervantes-Gloria Y, González-Mendivil E. Sample Size Estimation for Statistical Comparative Test of Training by Using Augmented Reality via Theoretical Formula and OCC Graphs: Aeronautical Case of a Component Assemblage. *Proceedings HCI International 2011*. *Lecture Notes in Computer Science* 2011; **6774**, (Ed.: R. Shumaker) Virtual and Mixed Reality part II - Systems and Applications, pp. 80-89.
2. Suárez-Warden F, González-Mendívil E, Cervantes GY. Assessment of Communicative Learning via Augmented Reality versus Traditional Method for Aeronautical Transportation. In *IEEE Proceedings of 13th International Conference on Transparent Optical Networks (ICTON),* 2011 (pp. 1-4).
3. Azuma RT. A survey of augmented reality. *Presence: Teleoperators and Virtual Environments* 1997; **6**(4): 355-385.
4. Azuma R, Baillot Y, Behringer R, Feiner S, Julier S, MacIntyre B. Recent advances in augmented reality. *IEEE Computer Graphics and Applications* 2001; **21**(6): 34-47.
5. Neumann U, Majoros A. Cognitive, Performance, and Systems Issues for Augmented Reality Applications in Manufacturing and Maintenance. In *Proceedings IEEE Virtual Reality* 1998; pp. 4-11.
6. Raghavan V, Molineros J, Sharma R. (1999). Interactive Evaluation of Assembly Sequences using Augmented Reality. *IEEE Transactions on Robotics* 1999; **15**(3): 435-449.
7. Pang Y, Nee AYC, Ong SK, Yuan M, Youcef-Toumi K. Assembly feature design in an augmented reality environment. *Assembly Automation* 2006; **26**(1), 34-43.
8. Reinhart G. Patron C. Integrating Augmented Reality in the Assembly Domain - Fundamentals, Benefits and Applications. *CIRP Annals-Manufacturing Technology*, 2003; **52**(1)*:* 5-8.
9. Wiedenmaier S, Oehme O, Schmidt L, Luczak H. (2003). Augmented reality (AR) for assembly processes design and experimental evaluation. *International Journal of Human-Computer Interaction* 2003; **16**(3): 497-514.
10. Wang X, Dunston PS. Compatibility issues in Augmented Reality systems for AEC: An experimental prototype study. *Automation in Construction* 2006; **15**(3): 314-326.
11. Ong SK, Pang Y, Nee AYC. (2007). Augmented reality aided assembly design and planning. *CIRP Annals - Manufacturing Technology* 2007; **56**(1): 49-52.
12. Yuan ML, Ong SK, Nee AYC. Augmented reality for assembly guidance using a virtual interactive tool. *International Journal of Production Research* 2008; **46**(7), 1745-1767.
13. Caarls J, Jonker P, Kolstee Y, Rotteveel J, Wim van Eck. Augmented Reality for Art, Design and Cultural Heritage-System Design and Evaluation. *EURASIP Journal on Image and Video Processing* 2009; Article ID 716160, pp. 1-16. DOI: 10.1155/2009/716160.
14. Henderson S, Feiner S. Evaluating the benefits of augmented reality for task localization in maintenance of an armored personnel carrier turret. *In: Proceedings of 8th IEEE International Symposium on Mixed and Augmented Reality*, *ISMAR 2009*, pp. 135–144.
15. Henderson S,Feiner S. Exploring the Benefits of Augmented Reality Documentation for Maintenance and Repair. *IEEE Transactions on Visualization and Computer Graphics* 2011; **17**(10): 1355-1368.
16. Sorensen Soren, S. Augmented Reality for improved communication of construction and maintenance plans in nuclear power plants. *Nuclear Safety and Simulation* 2010; **1**(1): 269-274.
17. De Crescenzio F, Fantini M, Persiani F, Di Stefano L, Azzari P, Salti S. Augmented reality for aircraft maintenance training and operations support. *IEEE Computer Graphics and Applications* 2011; **31**(1): 96-101.
18. Nee AYC, Ong SK, Chryssolouris G, Mourtzis D. Augmented reality applications in design and manufacturing. *CIRP Annals - Manufacturing Technology* 2012; **61**(2): 657-679.
19. Federal Aviation Administration. *Workbench tools*, 2006. Available on: http://www.hf.faa.gov/WorkbenchTools/
20. The MathWorks, Inc. *R2012a Documentation of Statistics Toolbox – kstest:2012*. Natick, Massachusetts, USA Availalble on: http://www.mathworks.com/help/toolbox/stats/kstest.html.
21. Campbell JD, Jardine AKS. *Maintenance Excellence: Optimizing Life-Cycle Decisions*. NY, USA: Marcel Dekker, Inc. 2001.
22. Rios H, Hincapié M, Caponio A, Mercado E, González-Mendivil E. (2011). Augmented Reality: An Advantageous Option for Complex Training and Maintenance Operations in Aeronautic Related Processes. *Virtual and Mixed Reality part I - New Trends*, Lecture Notes in Computer Science **6773**. pp. 87-96.
23. Guerra Moreno MA. Applying Knowledge Management and Using Multimedia for developing Aircraft Equipment**.** *39º Congreso de Investigación y Desarrollo*, 2009; 346-347. Tecnológico de Monterrey - campus Monterrey. México.
24. Wackerly D, Mendenhall W, Scheaffer RL. *Mathematical Statistics with Applications*. Cengage Learning: Duxbury Press; 2001.