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Using VR to Improve the Design of Assembly Tasks and Increase Task Efficiency

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Abstract (300-500 words)

In this paper we discuss how theories of vision, touch, sound, and learning behavior can form a basis for the development of a testbed through which real-life task performance can be compared with task performance in a Virtual Reality (VR) environment. By taking a multi-sensory approach, it will be possible to simulate the functionalities of a real training setting in a VR environment. Approaching this problem from a theoretical perspective, we will view it from a new angle and discuss whether we can enhance and nuance feedback in the virtual experience through the use of ambient media like sound, scent, heat, and wind. Sound may hold a great potential here. For visual perception, it is not only crucial that we can see relationships but that we are also able to search for patterns that we recognize. If an object is taken outside its context, its meaning can easily shift. To see is to search for patterns, but vision is also dependent on our experience of other senses. We can imagine how a given surface might feel by looking at a representation of the object, and this is because of previous tactile experiences with similar objects. From a technical perspective, integrating sound in a virtual environment is a straightforward process. Research shows that the process of learning a series of physical actions can be enhanced when it occurs in parallel with verbal or written information. In the literature, this phenomenon is described in terms of enactment or subject-performed tasks. Based on theories regarding vision, touch, sound and learning behavior, we suggest the design of a testbed that can be used in a pilot study aimed at increasing knowledge on how VR and AR can support learning in an assembly or installation context in order to produce guidelines for such an environment.

Keywords: Virtual reality, augmented reality, learning behavior, multimodality

1. Introduction

Virtual Reality (VR) and Augmented Reality (AR) are more or less entirely visual mediums. It is possible to act and interact with the VR environment as well as its imaginary objects, which can be lifted, moved, pressed, and turned. However, the only confirmation that the interaction is taking place is received by the user's visual perception. When corresponding activities are performed in real life, on the other hand, one experiences other kinds of sensory input as well. For example, in a real life environment it is possible to perceive weight, density, friction, temperature, and texture. All of these aspects contribute to an authentic experience and create a feeling of presence among users. A large number of controllable parameters also creates conditions in which users can develop problem solving skills over time and learn to perform a task with increased precision.

By simulating various work tasks in a planned production or assembly line, it is possible to not only use the platform for learning and training, but also for the purpose of detecting inadequacies related to time and ergonomics. In order to create an efficient learning environment in VR, however, it is necessary to study which contexts and situations are most suitable, and how they should be designed.

Although a VR environment has limitations, it also introduces possibilities when it comes to creating an effective learning environment. Regardless of shortcomings based on the use of only one sensory input (vision), large benefits can be gained if costly or dangerous work tasks can be successfully practiced in a VR environment. For instance, VR environments have been utilized for assembly task training (Brough et al., 2007). The user receives guidance on how to conduct different assembly steps, and feedback is given when errors occur. VR environments have also been developed with the aim of improving the design of assembly processes, based on existing design methods and the analysis of performance data (Sung et al., 2009).

In this paper, we discuss how theories of vision, touch, sound, and learning behavior can form the basis for the development of a testbed through which real-life task performance can be compared with task performance in a VR environment. By taking a multi-sensory approach, it will be possible to simulate the functionalities of a real training setting in a VR environment. Based on the theories, we also suggest the design of a testbed that can be used in a pilot study aimed at increasing knowledge of how VR and AR can support learning in an assembly or installation context, in order to produce guidelines for such an environment.

2. Background

In order to systematically explore the most effective and efficient ways of using VR and AR in the manufacturing industry, theories from various fields must be taken into consideration. We have identified theories on the relationship between vision and touch, sound and sound metaphors, and learning behavior, as crucial to further understanding how VR and AR can be used in practice. With respect to perception and cognition, the use of VR or AR could provide increased possibilities. However, the technology needs to be applied in ways that support human senses and reduce shortcomings related to a lack of real life presence.

Visualizations can facilitate the interpretation or reading of simulation, which can be defined as a set of techniques—not technology per se—for augmenting or replacing the physical experience. How a simulation is experienced is dependent on the design of the visualization itself, as well as the interaction design of the interface (Ware 2012). VR is an altogether visual medium, but it is possible to act and interact with the environment and its objects. It is possible to lift, move, push, twist, and throw imaginary objects, but the only confirmation the user receives that the interaction is taking place is what they can see with their eyes. When the same actions are performed in real life, properties like weight, inertia, friction, temperature, and surface structure contribute to making the experience more complete, and give the user a sense of "presence." The amount of controllable parameters also gives the user the opportunity to develop greater task performance skills over time, and achieve increasing accuracy and precision.

Scholars have defined that which is required of a visual representation in order to be accepted as a representation of an object or milieu (Tversky, 2013; Bae & Watson 2013; Eppler 2013).

The challenge is to create a visualization that works efficiently and fulfills an organization's need to plan and control the work environment. In terms of knowledge, there is still much to be desired when it comes to learning about the use and contribution of the virtual tools in relation to different stakeholders, design phases, and various decision making scenarios. According to the concept of digital manufacturing in production systems, the passage of data from one department or discipline to another should be seamless, so that the data created are immediately reusable in a different discipline (Chryssolouris et al. 2009). Wöhlke and Schiller (2005) identified a need for research efforts in the early design phases, following their conclusion that the planning quality and degree of maturity during the early planning phases can be improved tremendously. Kehoe and Bougthon (2001) have defined six criteria for the design of efficient information: relevance, timelessness, precision, accessibility, understandability, and meaning.

Approaching this problem from a theoretical perspective, we will view it from a new angle and discuss whether we can enhance and nuance feedback in the virtual experience through the use of ambient media such as sound, scent, heat, and wind. We will also discuss the possibility of supporting expected motions performed by an operator in order to complete a task. By using the correct motions, the muscle memory will store the correct way to solve a given task (assembly or installation) and will later be able to support the real life performance.

Sound may have potential here, providing feedback to the person performing in a VR environment—especially when it comes to motions or various movements. From a technical perspective, integrating sound in a virtual environment is a straightforward process. This is to enable the development of VR environments that use knowledge about human learning to create tailor-made teaching programs.

3. Theories

3.1 Vision

Theories about vision have a long history which spans from ancient times to today. The focus of the theories has varied over time and the interest has been broad, covering areas such as oculars, optics, philosophy, art, literature and psychology (Lindberg, 1976). Some of the theories have built upon one another, while others have taken on a new direction entirely. During the renaissance, an interest in optics resulted in the development of perspective (Kemp, 1990), which made it possible to represent environments and objects through an illusion of, what we today define as 3D. In the area of engineering, design, and technical communication, with a focus on visual representation, a combination of drawings featuring isometric or two points perspective have been used, as well as orthographic projections (Ferguson, 1994). Many of the engineering drawings from the 18th and 19th centuries are very detailed and immersive. The drawings not only portray how to install or assemble an object, they show sceneries representing the actual milieu in which people interact (Ferguson, 1994). It is tempting to compare the old engineering drawings with contemporary VR environments. But it is essential to recognize the differences: "In virtual space, the parameters of time and space can be modified at will, allowing the space to be used for modeling and experiments" (Grau, 2003). According to Ferguson (2001), interpreting an engineering drawing is a decoding process. One needs to be experienced in order to know where to look and what to look for. An engineering drawing constitutes a language in itself, containing conventions and symbols that represent very specific details and expected actions.

Crucial to visual perception is the ability to see relationships, as well as search for patterns that we recognize (Arnheim, 1969). If an object is taken from its context it can easily shift in meaning. To see is to search for patterns, but vision is also dependent on our experience of other senses. We can imagine how a given surface might feel by looking at a representation of the object, and this is because we've had previous tactile experiences with similar objects.

In visual representations, an object or spices can be identified because of its shape or specific features. The recognition of a represented object is mainly dependent on one's viewpoint (Palmer et al, 1981). According to Ware (2013), object recognition has been developed by matching visual information with the mental image of objects from stored viewpoints. Viewpoints can be regarded as snapshots that allow for recognition, despite small geometric distortions in a picture that occur in perspective transformation (Ware, 2013). Extreme perspectives, however, can create unrecognizable pictures of known objects. An environment is only accepted as a representation if the spatial organization is the same as in reality. Plan drawings and maps are examples of abstract representations of specific spaces.

According to the Gestalt theory (Ware, 2013), in order to interpret the environment, humans look not only for patterns but also representations of it. Humans interpret objects, or parts of the same object with similar colors, as belonging to each other (Ware, 2013). It is the same for shapes—objects with more or less the same shape are understood as belonging to the same group, and if objects are depicted or located close to one another they are interpreted as being related (Ware, 2013). There are several principles in the Gestalt theory that are relevant for VR, and from which it is possible to gain insight into what and how VR can be used in an efficient way for learning and training. In computer-aided design (CAD) VR models, the various parts of an object or machine are often given different colors. Because of this, it is possible to separate one part from the other; although sometimes two parts are given the same color even though they are not related.

3.2 Touch

The skin is a very sensitive organ. Especially the lips, fingertips, and soles of the feet. Through touch, it is possible to detect invisible particles and very fine textures on a surface either by moving the fingertips on a surface or walking on various materials with bare feet. In addition, through touch we can experience texture, temperature, density, and weight. However, tactile decoding requires both motion and resistance, and that is what is defined as *haptic*. Until relatively recently, the interest in haptic perception has mostly been related to how and what blind people can learn from tactile input. The interest today is mainly related to technology and various interfaces geared towards sighted people. Like in vision, the interest in tactile perception has a long history (though not quite as long). Already in the 18th century, the philosopher Denis Diderot was showing interest in learning how touch works as a source of information (Eriksson, 1998). Even though the focus of research on tactile perception or haptics has been centered around people that are blind, much of the results from the early studies are highly relevant to the contemporary development of haptic feedback in VR.

Scholars have studied the ways in which touch can replace vision, or work in the same conditions. In 1920, David Katz conducted a study where he compared touch with vision and came to the conclusion that, "When we touch some common object, the tactile impression is always permeated with visual experience" (Katz, 1989, p.156). He also emphasizes how the movement of fingertips create touch (Katz, 1925/1989). In order to gain information from touch, movement is required. Passive touch is less efficient than active touch. Temperature is possible to experience without movement. But in order to recognize the quality of a surface, the density of a material, or the weight of an object, movement is required—and that necessitates muscle power. On the other hand, it is possible to experience aspects from touch that are not visible, such as a small irregularity on a surface.

Touch does not work at a distance. Tactile perception requires contact with the actual object, material, or surface. To what extent one can gain information from touch was explored by scholars already in the late 19th century (Eriksson, 1998) and the theories developed on tactile perception are still in use today (Heller, 1991; Kennedy, 1993; Millar, 1994; Eriksson, 1994; 1998; 2012; Eriksson & Fellenius, 2014).

Tactile exploration involves a kind of choreography. In studies of blind people exploring tactile pictures, it has been observed that even a change in a pattern of movement is important for recognition (Eriksson, 1993); especially if the exploration of a picture is simultaneously combined with a verbal description (ibid.). According to Dewey (who was influenced by Pierce), when we are dealing with a new and complex situation we do not exclusively use ideas or thinking to discern what is happening, we also use tools in order to physically reshape and understand the environment, as well as words to reshape the dynamics of the situation (Gallagher, 2009). David Kirsh (2004) summarizes Pierce's view, writing, "Thought is not just *expressed* in work, it is *executed* in work."

By utilizing experience gained from previous research in tactile perception, as well as the meaning of bodily experience in work task performance within the field of haptic output, and applying it to VR technology, it is possible to explore how a VR training situation can support the learning process. For instance, by teaching the motions that are needed in order to appropriately interact with a machine or in an assembly situation. It is possible to find out to what extent VR choreography and muscle memory can aid learning and transfer from VR to a real life situation.

Ever since the infancy of VR in the early 90s, researchers have striven to complement the visual experience with different types of haptic feedback. It has often been in the form of mechanical, motorized "arms" that are connected either to some type of hand controller (lever, steering wheel, game control) or directly to the user's hands or arms. The mechanism can then simulate resistance or create motions synchronously with the movements the user can see with their eyes in the visual virtual space (Massie and Salisbury, 1994).

Although these types of solutions may work well within the contexts they were developed for, they also carry obvious disadvantages. They are expensive, heavy, and bulky. And they are not generic, i.e., they must be designed for a specific purpose or at least for circumstances where similar movements and haptic feedback are required. VR systems that use haptic feedback, along with other kinds of feedback, to simulate an actual task might enhance trainees' risk of dependency on certain characteristics of the system, thereby destroying knowledge transfer from the virtual world to the real world (Rodrguez et al., 2012). On the other hand, studies conducted by Rodrguez et al. (2012) indicate that haptic feedback does not impair knowledge transfer. However, more research is required to learn how procedural tasks training can be conducted efficiently in virtual environments.

3.3 Sound

From a biological perspective, visuals constitute the largest proportion of all the information we collect in order to gain situational awareness. An estimated 40% of the brain's cortex is used to process visual information (Lennie, 1998), while approximately only 3% contributes to audio processing. Nevertheless, sound is extremely important, and can often mean the difference between an operational and dysfunctional VR application. Another difference between vision and sound is that we are more likely to benefit from audio information at a lower level of consciousness, while we become aware of visual events in a more obvious way. Because of that, sound also contributes more to our expectations and tensions over what we think will happen. For example, when the rain hits the window, a car engine suddenly sounds different, or a noise (or sudden silence) comes from the children's room. Sound puts us on standby, preparing us to act in new situations— before we even know it (Lipscomb, 2013). Michael Abrash from Oculus (a company that develops VR systems) stated that in VR, 3D sound is "not an addition, it's a multiplier." Everybody talks about VR in terms of "presence" and "immersion." The truth is that without a certain level of competence in audio design, there is no presence at all. What's more, because it is a multiplier, there is an extremely fine line between what we would call presence (the illusion that you're actually there) and annoyance (Taylor 2016).

There are often three different levels of sound in VR and computer games. The first level consists of "naturalistic" sounds: Sounds motivated by the environment the virtual world is representing. The wind whistles. The door opens. Engines are buzzing. This is traditional sound design, similar to the way sound is designed for movies, radio shows, etc.; but with the important difference that in VR, the sounds are interactive. Sounds should occur when a user interacts with the environment. Jean Sreng and Anatole Lécuyer describe how the contact between different types of virtual objects can be made to be more believable through sound design. For example, the sounds that occur from touching, colliding, and rubbing can tell the user what type of material the objects are made of, and provide hints regarding surface, friction, and density. (Sreng and Lécuyer 2013).

The second level is sound that provides feedback in a more abstract way; including non-realistic sound icons (often called "earcons"), like the beeps and clicks heard through the common operating systems of computers and mobile phones. We quickly learn how to use and react to these sounds, even though they do not originate from our physical world.

The third level of sound consists of background noise or ambient sounds, which are primarily used with the intention of achieving a certain feeling or putting the user in the right mood. Background noise can also often manifest in the form of music or musical hybrids.

A new and interesting approach could be to explore the possibility of a fourth level of sound, or perhaps another dimension of interactivity in some of the upper levels. Thanks to cartoons and computer games, there already exists well known, language-like conventions for how to use sounds, and how sounds should be interpreted by the audience when they are used for illustrating physical events. But we can also envisage a partly new area for sonic augmentation. For example, could it be possible to connect the attribute of weight to the frequency of a sound, so that heavier objects are accompanied by lower, more bass-like sounds, and lighter objects are accompanied by lighter, more treble-like sounds? Can we illustrate "friction" by letting the background noise become gritty or iterated? Or would the association work better in a completely different way? The above examples may seem simple or even a bit ridiculous, but if we just consider them as small components in the huge and complex system of audio and visual 3D information, it's possible they can meaningfully contribute to the creation of an easier and more realistic interaction, as well as to a more convincing sensation of presence.

3.4 Learning and Cognition

Research shows that the process of learning a series of physical actions can be enhanced when it occurs in parallel with verbal or written information. In the literature, the phenomenon is described in terms of enactment or subject-performed tasks (Cohen, 1981; Engelkamp & Krumnacker, 1980; Zimmer & Engelkamp, 1999). Studies have been conducted comparing recall with verbal tasks (VT) and subject-performed tasks (SPT), where subjects are also given instructions for performing actions with real objects. The results indicate that memory performance for SPT is higher than memory performance for VT (Cohen, 1981; Engelkamp & Krumnacker, 1980; Zimmer & Engelkamp, 1999).

As described above, going through the physical motions of conducting a practical task supports learning. VR has, for example, been shown to be effective for learning basic surgical skills (Yiannakopouloua et al. 2015). One benefit of VR, which is highly relevant to manufacturing, is the possibility of learning a process. A process learned in a virtual environment transfers well to performance in real life, as confirmed by study results showing a similar level of performance being achieved in conventional training compared to training in virtual reality (Ganier et al., 2014). VR can also be used to support decision-making. When critical situations which demand action are repeated in a VR environment, decision-making has been shown to improve (Duffy et al., 2004).

The acquisition of spatial knowledge and the learning of new environments have been shown to transfer from learning within VR to way-finding in real world environments (Bliss et al., 1997). Besides contributing spatial knowledge, VR may also be used as a tool for analyzing people's spatial behavior (Elisângela and Francisco, 2008) and underlying mechanisms.

VR applications have also been developed and used for therapy and treatment purposes. For example, for the treatment of phobias, such as fear of spiders, through cognitive behavioral therapy (Miloff et al., 2016). One advantage to using VR for this purpose is that non-real, less frightening situations can be simulated in the beginning of a treatment, lowering the threshold for starting the therapy.

Further investigation is needed to understand how aspects of learning and cognition are similar between real environments and VR environments; as well as to understand which aspects reveal transfer effects between the different environments. In order to create effective VR learning environments, these effects need to be investigated and taken into consideration. Knowledge needs to be collected regarding the extent to which the effect transfer is present or not in specific conditions. This is to enable the development of VR environments that use knowledge about human learning for tailor-made teaching programs.

4 Framework and Testbed Development

Manufacturing industries try to improve their competitiveness by implementing information and communications technology (ICT). The maturity of VR and AR element technologies has increased over the last ten years, and so too has VR and AR research in the context of New Production Development (NPD) (Nazir et al 2012). Virtual reality is being used in product development processes in manufacturing enterprises as a helpful technology for achieving a rapid consolidation of information and decision-making through visualization and experience (Baharet al 2014; Bordegoni & Ferrise, 2013). Virtual prototyping is a relatively recent practice used in various industrial domains, which aims to anticipate a product that does not yet exist in reality. This practice can be used for evaluating a product's aesthetic quality, as well as its functional features, and ergonomic and usability aspects (Manca et al., 2013).

However, there is a lack of research related to multimodality in the use of VR and AR in a manufacturing context. We suggest a test, and demonstration methods for the purpose of gaining new and deeper knowledge on the requirements needed for the design of visuals in VR and AR—as well as to gain knowledge on when tactile (haptic) input and sound feedback is needed—in order to gain a full understanding of future products, how to assemble products (via training and learning), and how to plan a production system in the assembly order of a product.

Using a testbed, it is possible to enhance and facilitate the implementation of VR and AR in the manufacturing context. From there, we can gather knowledge about how and where in the supply chain these technologies should be implemented in order to achieve the greatest cost efficiency. Research questions to ask are:

- How can VR enable early contact between CAD-designer and production technicians in order to speed up the design process?
- How can VR be used as a tool for tighter and swifter communication between the end user and the system integrator to enable quick start up of production lines?
- How can the state of the art 3D visualization tools be used to achieve an assembly line without expensive and time-consuming fixture designs and setup allowing for quick design changes?

Both large companies and SMEs have a need to better understand how AR and VR can be used within the scope of their business. The testbed will also provide a learning environment where mutual knowledge exchange between large companies, SMEs, and research can lead to a better understanding of how VR/AR can be used in a cost efficient manner within manufacturing.

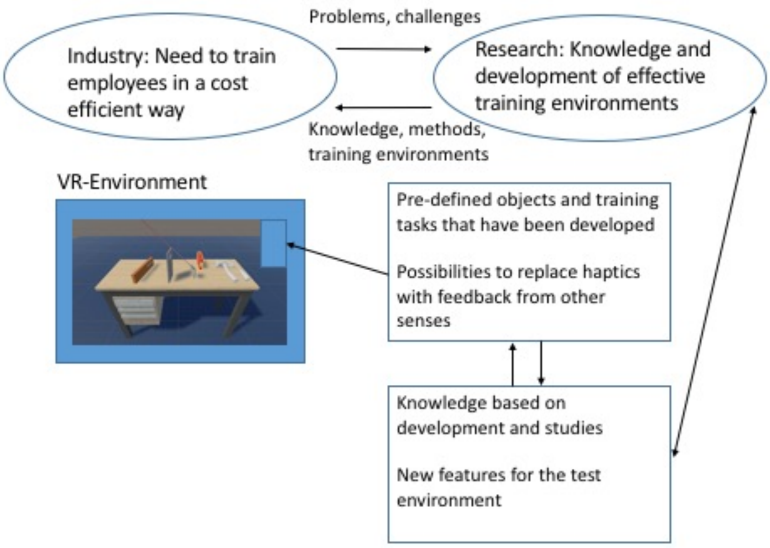

Figure 1: The work with the development of the testbed will be an iterative process, where new knowledge is gained in each test and used to generate new research questions and to improve the VR-environment and the study methods.

The testbed will consist of a VR-environment that supports an easy set-up of different manufacturing contexts. Within this environment parts of the processes to be taught can be tested and explored; both in terms of which parts that are feasible to train within a VR-environment and with respect to how the learning tasks can be implemented to be as effective as possible (See figure 1).

Through the testbed, we aim to explore how elements such as color and viewpoint guide the user's attention in a VR environment; as well as if and how an inconsistent use of color hinders the ability of the user to interpret objects and the environment in a proper way (Palmer et al, 1981; Ware, 2012). Since different parts of an object are often separated by color, we want to study whether or not it hampers the decoding of assembly instructions. VR allows the user to turn around an object, which often leads to a non-canonical representation. In what way does this ability have a negative effect on the user? It could be that a canonical view should be suggested at some point in the VR environment in order to support the user's decoding process.

Sound and visual input can be mutually supportive, but they can also interfere with one another. In a testbed, it is possible to explore how sound and visuals can interact in a coherent way. Like colors, sound metaphors need to be used in a consistent way and one sound cannot have different meanings, especially within a single context. From theories of cognition and learning, we know that muscle memory plays a crucial role in learning through practice, such as in handicrafts, etc. Since it is not possible to use virtual touch without assistant devices, we will explore the potential of using the choreography of specific movements that are involved in an assembly situation or installation process. Will the way in which an operator learns to perform a specific motion in a VR environment be helpful in a real life situation? Finally we will also explore how sound can enhance or replace the lack of haptic feedback.

5 Conclusion

Many companies have identified VR and AR as priority areas. However, there is uncertainty as to how, when, and in what way VR and AR can support business. Big winnings can be made if costly and/or dangerous operations can be successfully trained for in a VR and/or AR environment. By simulating different work moments in a planned production line or assembly line, deficiencies can be discovered regarding both time and ergonomics. However, there is no basic knowledge of how the VR and AR environments should be designed in order to support different learning and implementations of different workstations. In order for a VR learning environment to work efficiently, investigation is needed to gauge the contexts in which VR is a suitable way to go and how the different environments should be designed efficiently. A VR environment presents both limitations and possibilities in relation to a real life learning environment.

Based on theories regarding vision, touch, sound, and learning behavior, we recommend the design of a testbed that can serve as a pilot study aimed at increasing knowledge on how VR and AR can support the learning of assembly or installation, in order to create guidelines for such an environment. This will provide an opportunity to exploit VR environments and learn how to compensate for the restrictions that exist; for example, regarding haptic feedback. From a testbed used for testing and demonstration, it is possible to explore to what extent hand movements are reflected in the virtual environment and can have the same memory enhancing effect as hand movements performed in a real life physical environment. Additionally, such a testbed could provide insights on how sound feedback can be used to support the learning process. We suggest that training in a simulated environment can become just as effective as training in a real life industrial environment.

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