Passive Haptic Feedback for Manual Assembly Simulation

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Passive haptic feedback for manual assembly simulation

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Abstract

In this study movable props representing an object were used to try to achieve realistic movements of a worker during completion of a manipulation task in an assembly-like scenario recreated in a mixed reality environment. The form and the weight of the movable props were adjusted to different resemblance levels. The effect of these levels on the experiential fidelity of the worker and on the action fidelity of process observers was studied. Results showed that increasing the fidelity of the movable props does not necessarily result on better performance, e.g. simulating the weight of the actual object only seems to improve the experience if the prop also resembles the form of the actual object. Further study is suggested to better understand the effect of other factors.

Keywords: Manual Assembly Simulation; Assembly Planning; Assembly Verification; Motion Capture, Mixed Reality.

1. Introduction

1.1. Motivation

Physical functional prototypes in the automotive industry are used to validate and verify different requirements. In production planning prototype building is used to evaluate, verify and optimize the planned manual assembly processes. Typically, the production planning team conducts a series of prototype builds, i.e. manual assembly process verification workshop, where the planned manual assembly process in the form of an operation list is walked-through, executed by a worker and evaluated by specialists in fields like ergonomics, quality and assembly time. At the end of these workshops an optimized process is defined for the start of production.

OEMs are increasingly offering more models, but since early prototypes are very costly, the number of prototypes available in the early stages of production planning is actually being reduced. Thanks to the availability of digital models of the product, and of analysis and simulation tools, it is already possible to address various buildability issues before any physical prototypes are built. Nonetheless, a thorough and comprehensive evaluation and verification of the planned manual assembly process using digital models and tools is still difficult, due to the variety of available approaches and their inherent weaknesses [1].

1.2. Simulation in manual assembly process verification

A typical simulation approach is to use digital human model (DHM) tools available inside PLM software, e.g. Delmia. However, these tools tend to be very time consuming and difficult to use, since manual set up of various degrees of freedom in each DHM's joint for several postures is required. Alternatively, the movements of a real person can be acquired, digitalized and mapped onto the DHM using motion capture technology. Motion capture reduces the modeling effort and increases the realism of the simulation as well as the validity of the results [1–2].

Using motion capture implies splitting the worker and potentially also the product into the physical and digital

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domains, in contrast to the prototype based approach where both are physically available or to the DHM in PLM software approach where both are digitally available (see [1] for a characterization of various manual assembly process simulation approaches). For instance, motion capture allows using physical props to enable a more realistic interaction of the worker being tracked with the virtual environment where the digital models of the product, the worker and other assembly relevant objects are available [2].

1.3. Haptic feedback in manual assembly simulation

Haptic feedback can be used to enrich the interaction with a virtual environment by simulating touch and force and feeding them back to the user via an input/output device tracking the worker's intentions and providing a proper response [3]. Further differentiation into passive and active haptic feedback is possible. Passive haptic devices are physical objects that provide feedback simply by their shape, weight, or other inherent properties, while in active devices the feedback is computer generated [4].

It has been shown that using haptic feedback alongside visual feedback for simulating manual assembly tasks in virtual environments improves performance and decreases discomfort and difficulty [5]. It has also been found that using active devices to simulate force between parts during assembly improves performance compared to the situation where only contact between the hand and the virtual parts is simulated by stimulating the fingertips [6]. Nonetheless, active haptic feedback requires the use of complex and expensive devices, which are usually spatially limited and do not provide an intuitive interaction with the virtual environment [7]. The use of a physical prop providing passive haptic feedback in combination with an active device has been shown to improve performance, experience and interaction ratings [8].

1.4. Props as passive haptic feedback

Passive haptic feedback can easily be provided by means of props representing the objects relevant to the manual assembly simulation. It can be differentiated between movable and static props. Static props are nonmoving physical components providing orientation and contact feedback to the worker, e.g. objects representing the body in white or the material racks. On the other hand, movable props are mobile physical components that can easily be handled by the worker, e.g. objects representing assembly parts or tools.

Nonetheless, the amount, complexity and type of props required to achieve realistic simulation of manual assembly processes remain largely undefined [2]. In [2] the required complexity and detail of physical props to capture and accurately reflect manual assembly tasks was analyzed by comparing postural differences under different levels of physical propping during a motion capture study of a manual assembly process simulated in a virtual environment. The propping aimed at providing static props for physical hard-points. Two levels of propping were studied, i.e. one providing minimal orientation cues and another one realistically depicting the base part and providing support points. Results showed that in tasks where the worker requires leaning-on or holding-up, the latter condition achieved more realistic postures thanks to the interaction possibilities brought up by the props.

Similarly, it has been shown that interacting with dynamic props significantly improves task performance when compared to interacting only with virtual objects in spatial cognitive tasks, bringing performance closer to that of completing the task in reality, and making task interaction more similar to the real world task, see e.g. [9]. On the other hand, if too many props need to be manufactured and used, enriching the interaction with the virtual environment through props might play against the advantages of digital simulation approaches. It has to be determined how detailed this props have to be, so as to allow the assembly planning team to properly evaluate and verify the planned process. It has been shown that due to the strong impact visual feedback has on perception, accurate haptic feedback might not be essential for a realistic virtual experience, see e.g. [10].

2. Aim of the Study

This paper concentrates on evaluating the resemblance level required by dynamic props during a manual assembly-like task. Given that during manual assembly process verification several observers evaluate the process, the study focuses on the effect these different resemblance levels have on the observed behavior of the simulated worker. Experiential fidelity, i.e. presence, and fidelity of performance, i.e. action fidelity, are both addressed during this study. It is expected that a higher sense of presence will render more realistically perceived actions.

It is not the focus of this study to determine whether or not the test subject representing the worker completes the process with different movements depending on the prop resemblance condition, what it is investigated is whether or not the observers perceive these differences. It might occur that different levels of presence result in different body movements, but the differences between them could be so small, that the observers will not perceive them. During this study experiential fidelity is evaluated through test subjects representing the worker (see Experiment 1), and action fidelity through external process observers (see Experiment 2).

Table 1. Combination possibilities for the different fidelity levels of the movable props. + resembles real condition, - does not resemble real condition. Condition E is the actual object. Condition X is empty-hand.

Condition	Weight	Form
A	-	-
B	-	+
C	+	-
D	+	+
E	Real	Real
X	No	No

Two factors are considered to determine the resemblance level of the dynamic prop to the represented object, namely form and weight. The combinations of factors to be studied are presented in Table 1. Notice that the actual object, i.e. condition E, and an empty-hand condition, i.e. condition X, are also considered. Cardboard boxes are used to depict the form. So as to depict the weight of the actual object these can be filled with ballast. See Fig. 1.

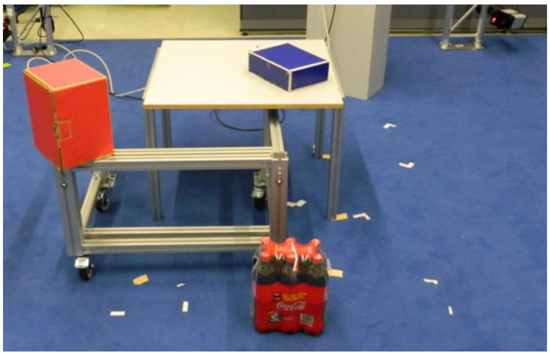

Fig. 1 Movable and static props. Box on the left resembles the form of the actual object. Box on the right does not resemble the form of the actual object. Soda six-pack at the bottom. Table represents the trunk surface. Aluminium structure represents the position of the bumper.

3. Experiment 1

3.1. Test scenario and set up

The worker, i.e. the test subject, executes a process using different movable props representing the object to be handled and positioned. So as to track the worker and the movable props the software RTI Delmia V5 from Haption along with an 8-camera ART tracking system are used.

The worker and the props are visualized in Delmia V5. The movements of the worker are mapped onto the DHM, the field of view of the DHM is used as visual feedback for the test subject. In this case a soda-six-pack (7,5 Kg – 320 mm x 240 mm x 140 mm) is the object to be represented by the movable props. The model of car used is the current Mercedes-Benz C-Class.

In Fig. 2 the soda-six-pack, the car and the DHM in the virtual environment can be seen. Following the results of e.g. [2] and [8], props providing passive haptic feedback are used to provide orientation, as well as slide and lean-on surfaces. These props depict the trunk, as well as the bumper of the car (see Fig. 1).

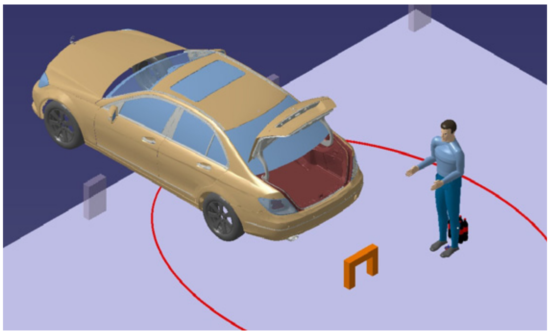

Fig. 2. Virtual environment representation of the test scenario. C-Class with the open trunk, DHM, bridge and actual object.

So as to eliminate the need for experience in manual assembly and to generalize the results, the scenario depicts an every-day situation, but it is designed to resemble a manual assembly task in automotive industry. Two tasks are planned:

- Task 1: Move soda six-pack through the bridge (in orange in Fig. 2), which resembles handling an assembly part.
- Task 2: Place soda six-pack on the right-rear corner of the trunk, which resembles positioning an assembly part inside the car body before final assembly.

3.2. Experimental design and procedure

The sample consists of 4 volunteer males (22–30 years old) employed at Daimler AG with no assembly planning or motion capture experience. The execution order of the different conditions (i.e. A through D in Table 1) for each participant is determined by a Latin square permutation. For all participants an empty handed condition is conducted before the permutation. After the permutation an actual object condition is completed.

Before performing the experiment, each subject fills the immersive tendency questionnaire (27 items Likert scale 1–7), is measured to adjust the size of the DHM and dresses with the tracking suit. After calibrating the DHM with the tracking suit the subjects are allowed to explore and get familiar with the virtual environment. Once they feel ready, the tasks are explained and the different conditions are executed. After each condition is completed the experiential fidelity is measured by asking the test subject to fill out the presence (7 items Likert scale 1–7), effort (9 items Likert scale 1–7) and difficulty level questionnaires (difficulty level scale 0–220). A closing interview is conducted to document further remarks.

4. Experiment 2

4.1. Test scenario and set up

The captured motion data from Experiment 1, see e.g. Fig. 3, is used to let the DHM in Delmia V5 execute the tasks inside the virtual environment. A total of 48 videos are made, i.e. 4 test subjects, 6 conditions per subject, and 2 tasks per condition. All videos showing the same task are created using the same camera perspective. Each video lasts approximately 10 seconds. Standard commercial video recording and playback software is used for this purpose.

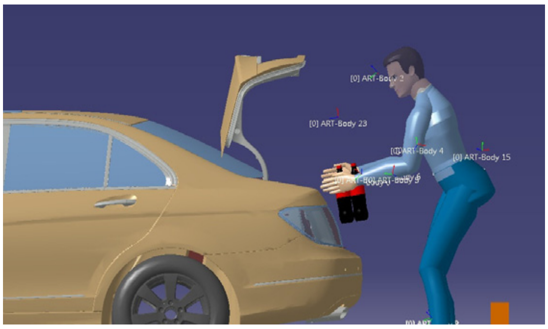

Fig. 3 Process execution of task 2 inside the virtual environment

4.2. Experimental design and procedure

A total of 16 volunteer observers (age average 27.88, 25% females, 50% university students, 50% Daimler AG employees) are asked to rate the realism and the similarity of the videos. The show order of the videos is determined by a permutation of the worker and a variation of the task order. After explaining the procedure the realism of the standard video, i.e. the video depicting condition E, is rated (Likert scale 1–7). Then each video depicting the other conditions is shown to the observer in the predetermined order. The observer then rates its difference to the standard video (Likert scale 1–7).

During the rating process, the standard and the rated videos are constantly shown to the observer. No time constraint is placed to complete the rating. All observers complete the rating within 60 minutes. After rating all videos an interview is conducted to document further remarks.

5. Results

5.1. Experiment 1

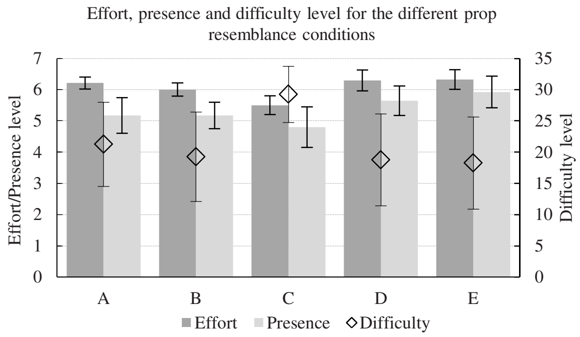

Fig. 4. Results for effort, and presence and difficulty level of experiment 1. Effort and presence levels are shown on the left scale. Difficulty level is shown on the right scale. Error bars show one standard deviation. Notice that for effort level a lower value means a task required more effort to be completed

After analyzing the results of the immersive tendency and presence questionnaires for each test subject, it is observed that for 3 of the 4 subjects a higher immersive tendency corresponds to a higher perceived presence. On the other hand, results reveal condition C as the most difficult (mean difficulty level 29.25) and E and D as the least difficult (mean difficulty level 18.25 and 18.75), see Fig. 4.

Results for effort level also reveal condition C as the one requiring more effort to be completed (mean effort level 5.50) and condition E and D as the ones requiring less effort (mean effort level 6.32 and 6.29), see Fig. 4. Notice that for effort level a lower value means a task required more effort to be completed. Presence level showed a similar behavior with condition E and D reporting the highest value (mean presence level 5.92 and 5.64) and condition C the lowest (mean presence level 4.80), see Fig 4.

5.2. Experiment 2

So as to avoid difference ratings to to be a consequence of tracking artifacts the results of the realism ratings of all the standard videos are first analyzed (mean 3.37 stdev 0.61). Standard videos rated below the average minus one standard deviation, i.e. below 2.76, are identified and excluded. As a result 4 standard videos remain, i.e. 3 standard videos of task 2 for test subjects 1, 3 and 4 and the standard video of task 1 for test subject 3, all these videos are rated with a realism higher than 3.

The realism of the 20 videos to be compared (conditions X, A, B, C, D) is rated at 4.08 mean value (stdev 0.52) and all are within one standard deviation of the mean. A repeated-measures-ANOVA for task 2 reveals a significant effect of the condition treatment. A multiple comparison t-test with Bonferroni correction shows significant higher difference rating for condition X (mean 4.21 stdev 0.81) than for conditions A (3.50 0.80), B (mean 3.25 stdev 0.86) and D (mean 2.73 stdev 0.84), significant lower difference rating for condition D than for conditions X, A, B and C (mean 3.75 stdev 0.69), as well as significant higher difference rating for condition C than for condition B.

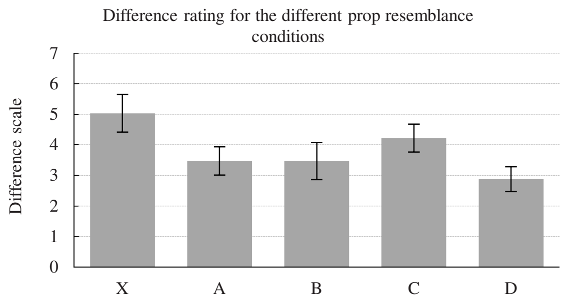

Fig. 5. Results for difference rating to standard videos for experiment 2. Results show the aggregate difference level of task 1 and task 2 for test subject 3. Error bars show one standard deviation.

The difference ratings for the videos of test subject 3 for both tasks and the five conditions (see Fig. 5) are analyzed with a repeated-measures-ANOVA revealing a marginal significance of the task treatment, the difference rating for task 1 (mean 3.96 stdev 0.70) being higher than for task 2 (mean 3.66 stdev 0.68), and a significant effect of the condition treatment. A multiple comparison t-test with Bonferroni correction shows significant higher difference ratings for condition X (mean 5.03 stdev 1.24) than for conditions A (mean 3.47 stdev 0.92), B (mean 3.47 stdev 1.21), C (mean 4.22 stdev 0.91) and D (mean 2.88 stdev 0.81), as well as significant lower difference ratings for condition D than for conditions X and C. In this case difference ratings for condition D do not significantly differ form those of conditions A and B.

6. Analysis and Discussion

6.1. Experiment 1

Experiment 1 addresses experiential fidelity, which is a subjective measure mainly based on presence, i.e. a state in which virtuality is not perceived and the attention is focused on the virtual environment. Since for experiment 1 only four test subjects were available, all results are not statistically significant and the analysis has to be understood as qualitative. It was expected that the more information the user receives, i.e. the higher the resemblance of the movable prop, the more presence would have been perceived. Nonetheless, condition C appears to be the most difficult and reports the lowest presence level in spite of closer resembling the actual object than e.g. condition A. As expected, the results for condition D are closer to those of the actual object.

Results appear to show that for the test subjects it is more difficult to manipulate movable props with a form differing from the represented object. This might be due to the need of paying more attention to the effect the prop's movements have on its counterpart in the virtual environment. Adding the right weight to the differing form appears to only worsen things, this might be the result of an increased difficulty to control the actual object in the virtual environment and the need to apply different handling strategies to complete the tasks. Fig. 6 depicts these findings.

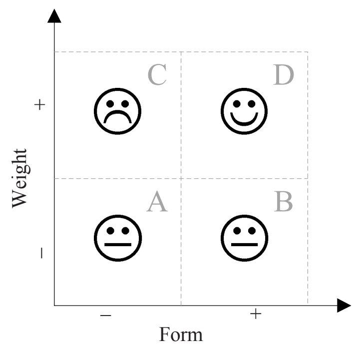

Fig. 6 Qualitative trends for presence, difficulty and effort in experiment 1. Condition C seems to be the most difficult, in spite of resembling the actual object more than condition A.

6.2. Experiment 2

Experiment 2 addresses action fidelity by studying differences that might appear during task execution under various movable props resemblance conditions. Unlike other studies where objective measures like skeletal-joint angles or time to complete a task are used, here the subjective rating of observers is used to rate the differences. The reason for doing this is that during manual assembly process verification mostly subjective ratings performed by observers take place.

As expected, the condition X, i.e. empty-handed, shows higher difference ratings than any of the other conditions. However, no significant difference between condition X and C for task 2 is observed. In the same way condition D, i.e. the highest resemblance level, shows less difference than the other conditions.

A higher difference rating for task 1 might be a result of tracking artifacts due to occlusions that could not be avoided when the test subjects squatted down to complete the task.

An unexpected and important result of this study is the fact that movable props resembling the right weight of the actual object, but not resembling its form do not appear to cause actions on the test subject that could be perceived by the observers as realistic. The action fidelity for this condition is the lowest and at practically the same level of using no prop at all. Increasing the resemblance level of the props does not necessarily result in increasing the realism perception of the executed task, e.g. condition C has a higher difference rating than condition A, while condition A and B do not significantly differ from each other. Fig. 7 summarizes these findings.

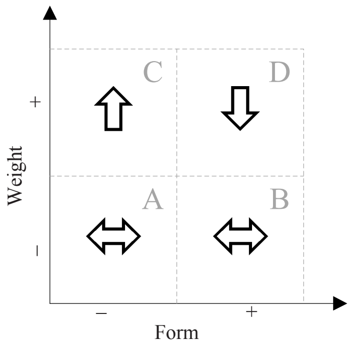

Fig. 7 Perceived difference trends for difference ratings in experiment 2. While condition C causes the most discernible differences and condition D the least discernible, condition A and B cannot be differentiated.

It is worth pointing out that the advantage of resembling the right form is more obvious for task 2. This might be due to the fact that the obstacle in task 1 is only virtually available, while a static prop for task 2 is provided. In task 1 the test subject needs to rely more on the virtual environment and the visual feedback to complete the task. Since constant visual control of the virtual object is necessary, the fidelity of the movable prop might play a lesser role. On task 2 the static props provide orientation and haptic cues, thus reducing the need to check the virtual environment and allowing to rely more on the passive haptic feedback provided by the props, letting the form of the movable prop play a greater role in completing the task.

7. Summary and Outlook

Using movable and static props for simulating manual assembly processes in mixed reality environments increases the performance and results of such simulations by providing passive haptic feedback to the subject representing the assembly worker and depicting closer to reality movements to observers evaluating such processes.

During this work, the effect of the resemblance level of movable props on the execution and perception of manual assembly-like tasks was analyzed. Two characteristics, namely form and weight, were used to create the movable props representing the object and were analyzed under two different experiments.

Results showed that increasing the resemblance level of the movable props does not necessarily result on a higher presence level during task completion. Simulating the weight of the represented object only seems to improve the experience if the prop also resembles the form of the object. Test subjects found it difficult to interact with props resembling the weight, but not the form of the object. In the same way observers perceived more differences under this condition.

Further study is required to analyze other effects of the virtual environment, such as the type of visual feedback and tracking technology. The results of this study will be used as a starting point to further investigate the resemblance level of movable props and its effect on manual assembly simulation performance. In addition to this, a use-case based study of an actual assembly task could be addressed with the help of manual assembly experts so as to validate and further understand the use of passive haptic feedback for manual assembly simulation.

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