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Accuracy and immersion improvement of hybrid motion capture based real time virtual validation

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Abstract

Using a digital human model for dynamic analysis is due to the high modelling complexity in digital environments not very prevalent. The movement of the worker is either unrealistic, or time-consuming to realize. Therefore, the need for research is a time saving possibility to explore virtual validation by a human model taking advantage of a nonetheless realistic movement design. To achieve this goal, we use an experimental setup including both a hybrid motion capture system and an interface for the connection to digital validation software. The motion capturing in connection along with the validation software allows real time modelling respectively tracking and therefore a realistic movement of the human model. To get good results while applying the motion capturing approach in mixed reality situations, it is necessary to have an exact registration between the real and virtual environment. Hence, the experimental setup must be designed for both. The key challenge here is to superimpose the CAD data with the real objects used for haptic feedback and better immersion. To realize an optimal registration we use a laser tracker solution.

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Keywords: assembly; simulation; mixed reality

1. Introduction

Virtual validation of manual assembly operations is not very common as a result of the high amount of time spent on generating transient human model simulation [1]. For generating a one minute of an animation of a digital human model with standard human model software tools typically 300 minutes of teaching are needed [2].

There is a high interested in alternative input devices for optimizing the manipulation of the digital human model. For example this is done by motion capturing, data gloves and haptic devices. The manipulation improvement should be mostly focused on body posture, hand posture, animation of the human model movement and the generation of libraries. The level of realism is especially important for animations. [3]

By connecting digital human models via motion capturing to a user, it is possible to control the avatar in real time [4].

The resulting challenge is to interact with the virtual environment. At this juncture, immersion is the key performance indicator for virtual validation systems using motion capturing. On the one hand, stereoscopic visualization must be implemented to enable visual immersion. The visualization of the virtual environment generates the effect of being part of the scenario. Especially for virtual assembly experiments, it is necessary to display the digital scenario right in front of the actor using a first person view. On the other hand, haptic feedback is needed to help the actor in the capture volume to interact with the virtual environment. Indeed virtual scenarios are the aim, for some applications however, it is necessary to interact in a mixed reality environment. Hence, physical mock-ups (PMU) are located in the capture volume (CV). These PMU need to be superimposed by digital mock-ups (DMU). In early stages of the production engineering process only DMU are available. In this case the haptic feedback is difficult to generate, but not impossible. Nevertheless, in both cases it is indispensable to have

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a high accuracy between the worker's real motions and the resulting action in the virtual environment. Only high accuracy systems generate results that are meaningful enough to use them for assembly validation and ergonomic analysis.

To encounter the challenge of interaction with high accuracy we present different approaches. To ensure visual immersion we make use of a head mounted display (HMD) and implement it in the experimental setup. To guarantee high accuracy registration of avatar and worker at any time we present a Kinect camera based software. In mixed reality situations, we apply a laser tracker to correlate real and virtual objects. In virtual situations, the interaction is supported by collision detection using the voxel method [5]. Further, we describe some advantages, which result from implementing functions for interaction, e.g. attach and detach of movable objects, using python scripting.

2. Experimental Setup

The combination of mixed reality and optical motion capturing often leads to static or dynamic occlusion. Unfortunately, the detection of targets by cameras is sometimes blocked by the PMU during manual assembly. Hence, we decided to use a hybrid system. The system utilizes in general the more accurate optical as master system and, during occlusion, an inertial sensor system. We placed eight infrared cameras surrounding the capture volume on a two-floor item profile system. The cameras are divided in two sync groups and connected to the controller, see Fig. 1. The deviation in two groups is required, so that the cameras' flashes are not mutually disturbing each other. The controller triggers the IR signals for the sync groups with 480 microseconds delay for avoidance.

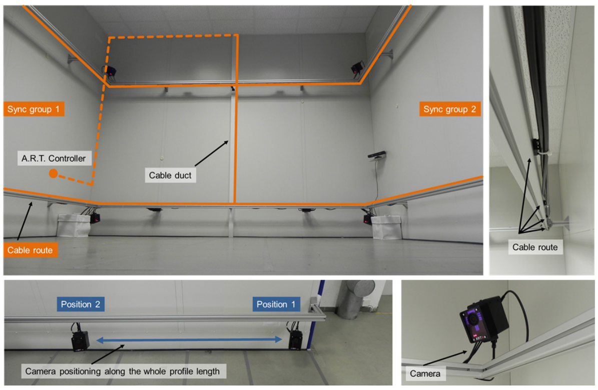

Fig. 1 Experimental setup of the hybrid motion capture system

The item system allows a situation-dependent repositioning of the cameras and is fixed in a 4x4x3 m cube, see Fig. 2 right. In addition the cube is being rigged with a vertical profile strutting carrying the WLAN antenna which is responsible for receiving the inertial data. Furthermore, a Microsoft Kinect camera is placed within the cube. Hence, it is possible for the operator outside of the CV to observe the actor. Another functionality of the Kinect camera is the attachment support, during superimposing digital human model and actor, and this will be discussed later in the paper. The actor wears a hybrid target suit for motion capturing, a cyber-glove for tracking the hand-finger system and a HMD for a stereoscopic view to the virtual environment.

Supplementary a moveable setup, see Fig. 2 left, is realized for tracking workers directly at their specific working environment, e.g. in a running production line or manufacturing cell.

Due to the sequential demands on high computing power of single applications, the IT is separated in the three platforms: Controller, Client and Server. The main task of the Controller is collecting and computing the tracking data to readable coordinates and sending them to the Dtrack2 software on the Server. The Server is mainly blocked for physics computation and collision detection. On the Client, the digital factory software DELMIA V5 and the interface software Haption RTID (Real Time Interface for DELMIA) runs. The distributed architecture communicates over Ethernet in two separated cables. For the real-time application, including the coupling of cyber-glove and motion capturing data the Haption RTID software is employed. With the DELMIA V5 human model, motion data can be analyzed. The output signal for desktop monitor, HMD and 3D projector is controlled and computed by DELMIA V5.

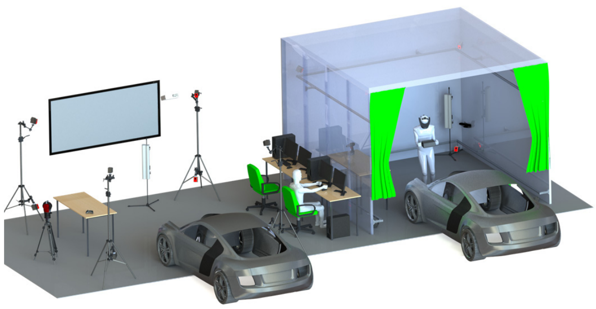

Fig. 2 Mobile (left) and stationary (right) experimental setup in CAD data

An operator and an actor control the system. The operator sits outside of the cube and controls the software during simulation. The actor wears the hybrid target suit and takes the assembly task inside the cube.

3. Immersion

To generate visual immersion we use a HMD. It enables us to stereoscopically visualize the virtual environment for the acting worker [6]. The worker does not need to suffer the limitations of desktop screens any more. Haptic immersion for virtual interaction is generated via collision detection and force feedback. Therefore, the Interactive Physics Simulation Interface (IPSI) from Haption is used. IPSI supports the solid-state physics including unilateral and bilateral conditions. Owing to the application of the collision detection library VPS (Voxmap PointShell) of BOEING [5] it is possible to handle complex surfaces. The collision detection works with the voxel method, which discretizes the room into a 3D mesh. Whenever two objects share the same mesh element, the indicator for collision will be exactly given. Employing the voxel method, collision detection can be visualized in real-time, depending on the element size of the mesh. For manual assembly simulation, collision detection is very helpful, especially for virtual investigations. Feasibility studies for placing a power electronics unit in an engine compartment are a good example for the need of collision detection [4]. The collision detection prevents penetration of active parts and visualizes the detection with vectors, see Fig. 3. For the interaction with CAD data, parts and products must be activated for moving and/or collision detection. By initializing only the necessary parts it is possible to interact in real time as computation power by meshing and detecting them is saved.

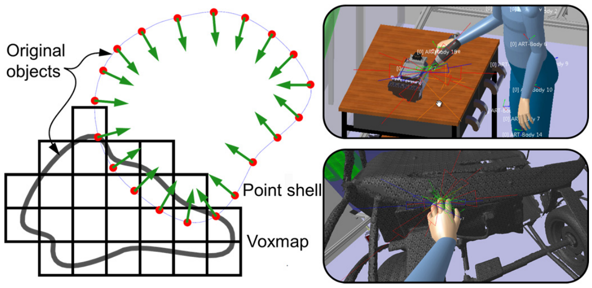

Fig. 3 Visual feedback of collision detection via vectors in the digital factory according to [5]

For a better performance, the software modules for collision detection are transferred to the server hardware.

For more immersion a sensible force feedback system is additionally initiated. Via RTID and IPSI scripting it is possible to activate force feedback, e.g. of a game pad. This is useful because the actor does not see every collision during the virtual assembly process. As result of the first person view, it is not possible to see collisions of legs with objects like the car body. In our setup, we used an Xbox 360 Controller to test the force feedback caused by collision. To be able to move objects in a virtual environment we also use the game pad. Python based scripts like attach and detach can be activated by the game pad buttons. It is also possible to run the scripts from the operator position. However, it is more comfortable and immersive to have it done by the actor himself. The example of grabbing an electric screwdriver is shown in Fig. 4.

In mixed reality situations, real objects are available in the CV, too. The PMU in the CV do not need to be fully developed hardware prototypes and thus functional models are sufficient, e.g. a tailgate model [7]. This generates more immersion given that haptic feedback is more realistic. Movable objects available as PMU, can be moved and tracked for the assembly. Therefore, it is necessary to bring PMU and DMU in correlation.

We tested the immersion improvement by the above discussed features implemented in the software. The consensus of opinion is an immersive virtual environment for virtual assembly simulation. The first positive aspect is the first person view via HMD. Stationary display based systems, e.g. Powerwall or monitor systems, lead to an incorrect head position of the recorded digital human model during assembly. This leads to complications in performing the process.

The virtual scene, stereoscopically displayed by the closed view HMD, enables higher immersion opposite to a see through HMD. The second important benefit is the force feedback during collision between avatar and object or object 1 and object 2. The visual feedback via the displayed vectors during collision helps to realize the consequences, but the force feedback is more immersion improving and helps for detecting collision that are not in the field of view.

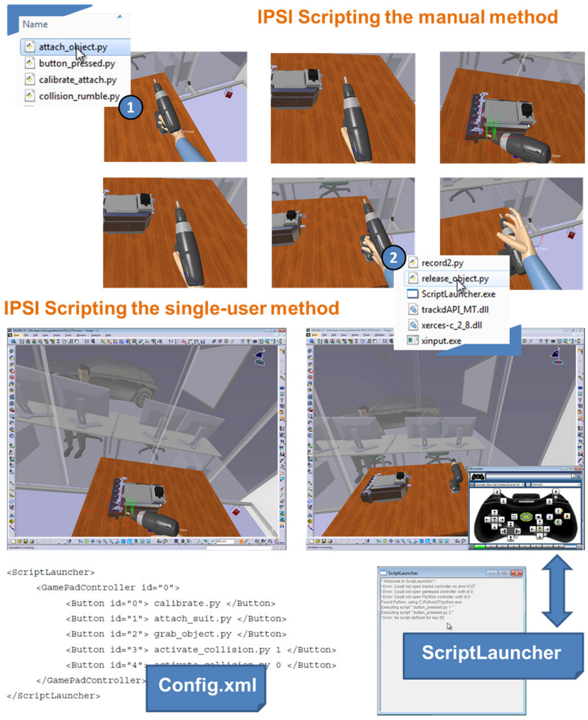

Fig. 4 IPSI scripting for virtual assembly simulation

4. Registration

To enable an accurate interaction, it is required to superimpose the digital avatar with the worker in the CV and the PMU with the virtual assembly environment.

4.1. Avatar and worker

The exact calibration of the avatar and the actor is important to generate high quality motion data. The preparation of arrangements like exact anthropometric data for the avatar and the precise adaption of the target coordinates are important. The calibrated targets are clearly recognizable displayed by a local coordinate systems and the corresponding target ID. The worker takes the exact pose of the avatar and brings the coordinate cloud of the targets in conformity.

The operator supports the precise alignment of the actor. He puts the camera view to the single limbs of the avatar and helps the actor during positioning. Subsequently the operator attaches the real actor to the virtual avatar. The calibration of the avatar must be done for each simulation and is a critical and time-consuming part. To improve the procedure an automatic calibration is developed. It is composed of the application software FAPSHolger with Python based connection to Microsoft Kinect. The Kinect matches the skeleton position of the actor with the defined posture of the avatar for calibration. When the actor is in the correct position a Python script activates the attachment. Figure 5 shows the graphical user interface of FAPSHolger and DELMIA V5. The correct position depends on 15 matching points. The correlation is visualized numerically and additional with colored squares. Another benefit in comparison to standard attachment is the correct head position, because the optical position check of feet and hands hoodwinks to looking down during registration.

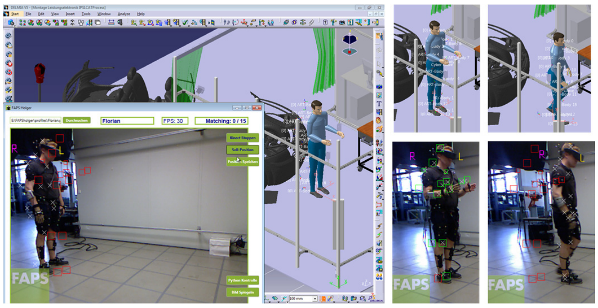

Fig. 5 Auto-calibration software FAPSHolger

4.2. PMU and DMU

The exact overlay of 3D CAD models to the real objects is called registration [8]. Deviations lead to a shifted representation and is named random error. This kind of errors is caused by the tracking system or faulty calibration. Errors caused by tracking system can be easily avoided by exact room calibration. The remaining source of errors is the object calibration. One possibility to correlate the real object with the DMU is called live registration, see Fig. 6.

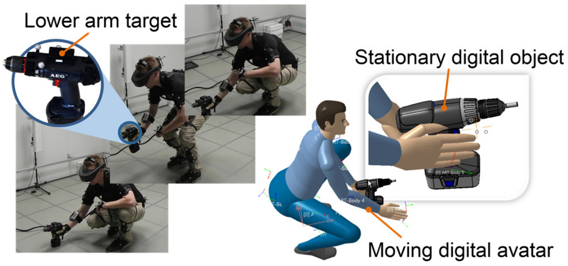

Fig. 6 Live registration of an electric screwdriver

The avatar attached to the actor is used to superimpose the PMU by moving it to the DMU position displayed on the HMD. This type of calibration is only useful for small objects. To position a vehicle body in this manner is difficult to achieve. The accuracy of live registration depends additionally on the avatar calibration. Registration using the avatar is a unidirectional process, too. Hence, the only possibility to reposition the PMU is during simulation.

The second occasion of registration is supported by laser tracking and enables higher accuracy. To achieve an exact correlation between real and virtual environment it is necessary to generate a global coordinate system (GCS) via laser tracking, see Fig. 7.

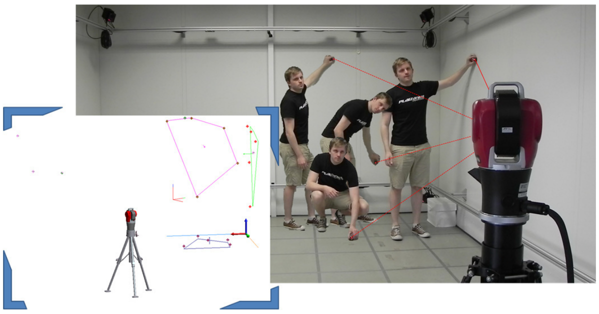

Fig. 7 Laser tracking for accuracy improvement of real and virtual environment

Referencing to GCS a structured mesh is mustered to the ground of the capture volume (CV), tracked by the laser and transferred to the CAD system. This kind of preparation can also be done referring to local coordinate systems, for example a structured mesh on a moveable table. The positioning of PMU can be achieved using the mesh on the ground while the DMU is being placed via the correlating virtual mesh in the CAD system. If it is not possible to use the grid for positioning objects by reason of their physical behavior or in case of an even higher accuracy, a direct laser tracking of the object is also feasible. Therefore, the laser tracker must be referenced to the GCS by using six permanently attached target nests. After referencing the laser tracker to the GCS, measured points on the object surface can be generated. The measured point cloud, transferred via STEP format to the digital environment, forms the boundary condition for virtually positioning the object, see Fig. 8.

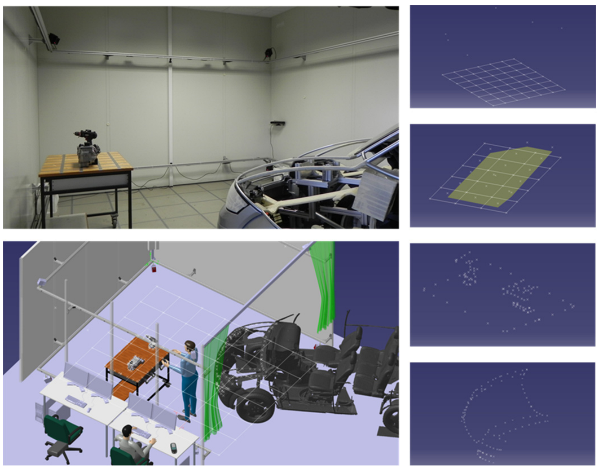

Fig. 8 Correlation between real und virtual setup supported by laser tracking

In our case, a demonstrator vehicle is put in the CV. The 3D-CAD model of the vehicle is scanned via Kinect camera and has small geometry deviations in consequence of the discretely-timed but composed scans. Since the front of the vehicle is critical to the assembly simulation, it is recommended to use the laser tracker for generating measure points of the relevant car parts for positioning. Placing the car by using the grid on the ground is difficult to handle and not as accurate as the direct laser tracker variants. Additionally the discrepancy between CAD model and real car could lead to further deviation, given that the tires must be used as reference and not the relevant surface of the front bumper.

5. Results

A virtual assembly validation system is presented, that combines advantages from different single systems, like virtual reality (VR) and CAD systems. The field of application reaches from virtual to mixed reality assembly validation. Based on CAD data the validation system has the advantage to use only one data structure. Sophisticated data preparation is no longer required. Detected errors and ergonomic findings during simulation can easily be corrected or optimized in the CAD system. In early stages of the production-engineering process, the virtual analysis helps to optimize a production oriented design and allows first ergonomic statements by using standard analyzing tools implemented in DELMIA V5, e.g. RULA, Lift-Lower, Push-Pull and Carry analysis. The validity of the ergonomic analysis is comparable to professional ergonomic analysis, as the motion of the digital human model is realistic in place and time. By supporting the haptic feedback trough mixed reality situations, the results get even more realistic. The assembly simulation can easily be optimized by using standard utensils like shelves, tables, and other assembly tools. Simple PMU can be used combined with exact DMU for better interaction. The assembly process of a power electronic unit is tested with this system in a virtual case as well as in a mixed reality case, see Fig. 9.

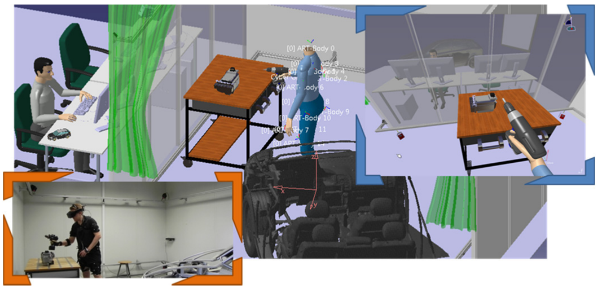

Fig. 9 Mixed reality situation in different kind of views

In both scenarios, we get realistic results attributable to the accuracy and immersion improvement described in this paper. The occlusion problem in mixed reality situations is solved with the hybrid motion capturing system, see Fig. 10.

We pictured out, that the purely optical system does not represent the realistic human arm position. The cameras do not detect the hand target anymore, whereby the arm posture of the last detected position is displayed. The hybrid system provides the correct data and thus a realistic picture of the human posture. Now we are able to investigate different kind of assembly problems in real time and with realistic results referring to the motion of the digital human model.

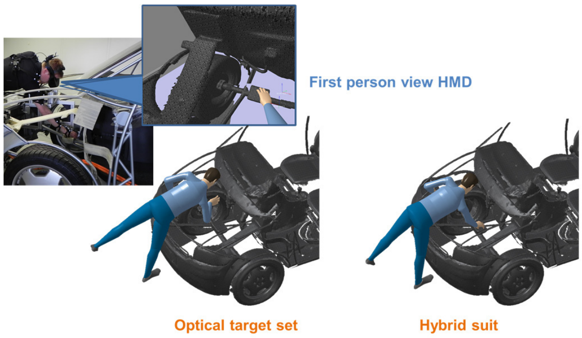

Fig. 10 Comparison between optic and hybrid motion capturing

We considered in our case study different assembly positions of a power electronic unit in a car front. Therefore it was necessary to optimize the system in the presented way, to be able to generate realistic and comparable results referring to varied worker and object positions. In this case study the car body is integrated as PMU and DMU. The interfering contour inside the front body exists only as DMU, because it is expensive and time consuming to produce as PMU, especially for varied scenarios.

6. Conclusion

In this study, the accuracy and immersion improvement of motion capture based virtual assembly validation is introduced. DELMIA V5 is the basis system for manual assembly simulation. This has several basic advantages over standard VR systems. One key benefit is the direct use of CAD data for simulation. Elaborate data conversion of updates is waived for the virtual assembly analysis. Using the digital human model of DELMIA as avatar enables collision detection of actor and DMU. Another advantage is the tool DELMIA itself. The different workbenches of the digital factory software are combinable with the human simulation, e.g. the manipulation of flexible parts is possible in the Electrical Harness Design respectively Simulation workbench of DELMIA V5. We are also able to simulate the human-machine interaction by using the robotics workbench fused with the human model.

The disadvantage of the CAD based software is the interaction with the virtual environment, especially the control of the simulation by the human model. This challenge is largely solved by the discussed approaches. The HMD allows a first person stereoscopic view, which is essential for interacting. IPSI facilitates the collision detection and thus the prevention of penetration. With the python-scripting interface, it is possible to integrate useful functions, e.g. easy-to-use attach and detach of objects, for manipulating the virtual scenario.

The Registration of avatar and worker is a crucial point, because the better the superimposing of real and virtual worker the more accurate and immersive the assembly simulation. Hence, the FAPSHolger software is developed to enable permanent high accuracy for avatar calibration with the benefit of time saving.

In mixed reality situations, the registration of real and virtual objects is supported by laser tracking. In the first place the real and virtual areas are correlated referring to a global coordinate system. Second, a reference grid is generated for the CAD system as well as for the CV. Using the grid PMU and DMU are placed referring to the correlating grid nodes in a very fast way. More accurate positioning is possible by using the laser tracker directly for position detection of the PMU referring to the global coordinate system. After generating measurement points, these points are transferred to the virtual environment and used for aligning the DMU.

Testing and optimizing the interaction and using other functions of DELMIA V5 in combination with motion capture based virtual validation will be presented in future work. Innovative hardware developed e.g. by the gaming industry can be integrated for improvement. The MYO gesture control armband of THALMIC LABS [9] for example uses the electrical activity of arm muscles to wirelessly control electronic devices. Integrating MYO instead of the gaming controller has the advantage of interacting freehanded. In addition, further useful features for assembly investigations or workplace design can be integrated by IPSI scripting.

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