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27th CIRP Life Cycle Engineering (LCE) Conference

# Virtual reality based digital chain for creating a knowledge base of hand gestures in maintenance tasks

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## Abstract

Hand gestures are key aspects in maintenance work. In this paper, we present a methodology for creating a digital knowledge base of maintenance hand gestures by applying virtual reality technology. Our motivation is rooted in the need to create work instructions that shall illustrate details of hand gestures that are the appropriate for particular maintenance operations. In this research, we propose an approach of recording, classifying and clustering such hand gestures in a library of gesture. Within this library, we can characterize each gesture and relate them to mechanical assembly and disassembly operations with respect to their appropriateness. Through this relationship, we create a knowledge base that can be used for suggesting hand gestures, as well as for rating them in e.g. training tasks. Furthermore, key elements of work instructions for operators can be derived from it. As a demonstration, we showed the process chain applied to the process of registration of hand gesture in simply maintenance task.

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**Keywords:** Virtual reality technology, Appropriate hand gesture, Library of Gesture, VR based digital chain ;

## 1. Introduction

Despite the trend towards remote maintenance tasks, largely facilitated by global high-bandwidth internet, a lot of mechanical installation still require frequent regular as well as occasional and urgent on-site maintenance and repair interventions. In particular, heavy and locally fixed installations such as ropeways and power stations are affected by this need. Driven by the globalization megatrend, these installations have seen a rapid worldwide expansion over the last decades. Along with this comes the need for rendering the maintenance tasks more sustainable in any of the three sustainability dimensions:

1. Social: Safety and security for the maintenance personnel, qualification and employment of local people, knowledge and skills transfer to developing countries, etc.

2. Ecological: reduction of ecological footprint due to long and frequent travelling activities of skilled personnel, as well as better and more frequently maintained installations.

3. Economical: increase of local economy thanks to local employment, huge savings thanks less travelling and preventive maintenance.

In addition to that, the increasing density and complexity of mechanical parts and assemblies makes maintenance tasks increasingly difficult and hazardous [1].

In order to address these challenges, we present a methodology for creating a digital knowledge base of maintenance hand gestures by applying virtual reality technology. In our previous work [15], we have specified the concept of a VR-TPP for preparing and executing VR-based maintenance training sessions. We used VR tools for capturing expert gestures, and we recorded the working process using virtual reality technology. In this process, we

realized that the quality with which specific had gestures can be captured and evaluated in the VR environment has a significant influence on the effectiveness of the training. In this paper therefore, we present a methodology for the classification and recording of hand gestures, as well as for organizing and storing the latter in a library for use in particular in the training preparation process. Within this library, we specify the definition of each hand gesture for use in the virtual environment and demonstrations we created.

We present our contributions in the following structure: section 2 will elaborate on related works, as well as why ours is complementary to those. In section 3 and 4, we present our hand gesture capturing and recording framework, as well as how we use it to build up a hand gesture library. Section 5 concludes and gives outlook on planned future research activities.

## 2. Related work

There is a lot of research trying to apply the virtual reality (VR) technology to increase efficiency, reduce costs as well as the risk in the training process in maintenance task [2-9]. Most of this research focusses on the overall picture of the training process, rather than digging into the details of the particular gestures applied during disassembly, assembly and any kind of special maintenance task. Appropriate gestures are the main factor for achieving the maintenance work successfully and safely. In fact, there are many research studies about the use of virtual reality technology for creating a virtual hand and applying it to various applications. Gan Lu et al [10], proposed development and evaluation of an immersive human-computer interaction system based on stereoscopic viewing and natural hand gestures. The system is enable a user to use a number of simple hand gesture to perform basic object manipulation task involving selection, releasing, translation, rotation and sealing. Mores et al [11], studied a virtual grasp and release method. They used heuristic analysis of finger motion and a transient incremental motion metaphor to manage a virtual hand during grasp and release. Thomas et al [12], described the basic algorithm for grasping with one or two hands and presented a method to manipulate the grasped objects between the virtual fingers. Xiao et al [13], proposed a hand gesture-based design interface for the review of CAD models in virtual environments. Their applications provide a natural and intuitive user experience in the CAD model manipulation. Although these researches described the characteristics of the gestures and hand usage, they do not mention the application of these gestures for designing and creating a work instruction. Most of these researches focused on using virtual hand technology only in during the training session. They do not address neither the training preparation phase nor the designing process of the work instruction. However, these phases are crucial for assuring the appropriateness of the virtual training, both in terms of VR technology used, and gestures actually trained. Jérémy et al [14], propose a new kind of tangible interface based on the handling of physical objects that they call “interactors”. They affirm that the handling of interactors can produce two kind of result. The

first is to give matter for reflection on the parts assembly operations. The second can lead to the proposition of different assembly solutions for the mechanical system studied.

## 3. Building a library of hand gestures

In [15] we introduced our Virtual Reality Training Preparation Process (VR-TTP) leveraging a systematic approach to creating a VR-based experimentation environment that facilitates the selection, calibration, and evaluation of different VR devices for the training of a specific maintenance operation. The VR-TTP consists of the four tasks Preparation, Execution, Implementation and Training, clustered in two phases, the Preparation phase and the Training phase. The preparation phase consists of the two tasks preparation and execution. The preparation task consists of the two modules Model Preparation and Work Instruction (WI) Making, while the Execution task consists of the four modules Recording, Translation, VR Using and Assessment, see Fig. 1. Our objective in this research is to facilitate the training preparation phase for maintenance tasks that involve special hand gestures for assembly and/or disassembly of basic mechanical joints.

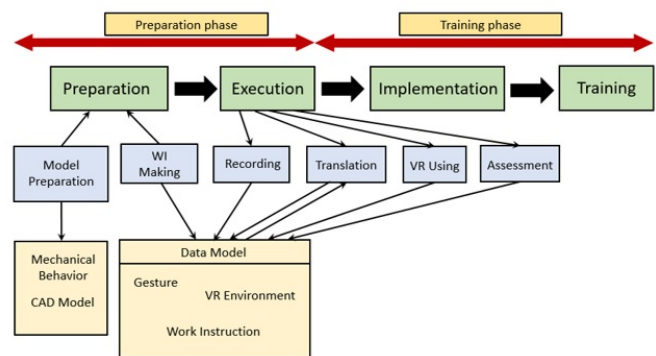


Fig. 1. Virtual Reality Training Preparation Process (VR-TTP).

This facilitation essentially relies on building a library of gestures classified per joint types that links expert gesture demonstration videos as well as textual work instructions to each joint type. This library can then be used both for the semi-automated creation of work instructions, as well as during the training process itself.

Our concept therefore focuses on applying VR technology to designing the process of creating work instructions facilitated by a knowledge base of maintenance hand gestures. This concept is effective and very useful in complex maintenance tasks where equipment preparation is very expensive and time-consuming and/or the setup and/or the maintenance tasks themselves are risky with respect to injuries. Applying VR technology in the preparation process before the training process can reduce time, cost, as well as the risk of accidents.

In order to understand the nature and importance of hand gestures, we need to identify the hand gestures that are appropriate for working and describe them with respect to their characteristics in an assembly and/or disassembly context. We set up a dedicated process for this, which is

depicted in Fig. 2. and we will describe in further detail in the following subsections.

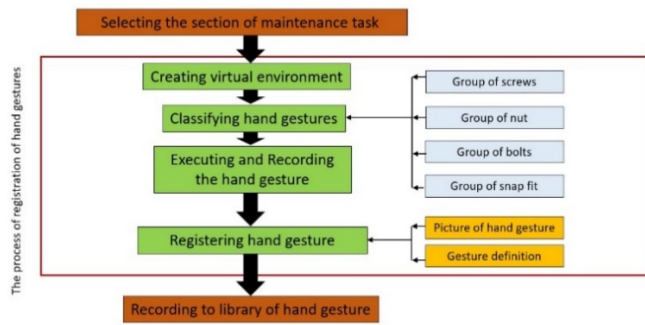


Fig. 2. The process of registration of hand gestures.

We implemented this process in a virtual reality environment using a laptop computer (Processor: Intel (R) Core (TM) i7-4750HQ CPU @ 2.00GHz (8 CPUs), ~2.0GHz, Memory: 16 GB of RAM, and NVIDIA GeForce GTX 950M: 4 GB of graphics card) running the commercial Unity game engine. 3D objects have been imported to virtual environment in OBJ format. To enable the user to realize the realism at the fully immersive level [16], we have chosen an Acer Mixed Reality head mounted display (HMD) and we used a Leap Motion device to track hand movements.

### 3.1. Selecting the section of maintenance task

As shown in Fig. 2, our process of classification and registration of hand gestures starts with identifying and selecting the maintenance task which we want to design and create the knowledge base of maintenance hand gestures for. In our case, we opt for understanding and documenting the most appropriate hand gestures required for assembling and disassembling mechanical joints. We decided for this case because it is universal, however it is just representative for any other usual or special types of mechanical parts that need special manipulation during the assembly and disassembly process. We built up a joint/gesture library on this basis, envisaging to continuously.

### 3.2. Creating virtual environment

Fig. 3 shows the mechanical joint models, we created in the virtual environment (from left to right): Hex Head Bolts, Socket Cap Screws, Hex Finish Nuts, Wing Nuts, Hex Lag Screws, Sheet Metal Screws, Wood Screws and a plastic box.

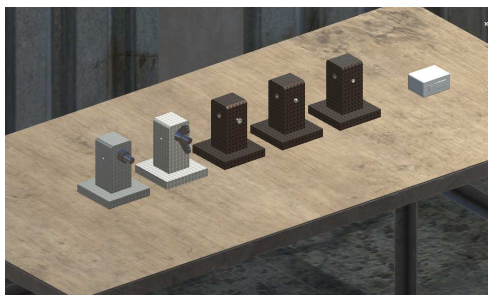


Fig. 3. Mechanical joint models in the virtual environment.

The reality level achieved by the virtual environment plays a crucial role in the training preparation process. It is important to make users recognize and accept the fully immersive level of virtual reality. Once we identified the maintenance task, we created a virtual environment (VE) that is close to the real work environment and therefore providing working conditions like in real situations. Fig. 4 shows the entire workplace model we used.



Fig. 4. The virtual workshop model.

### 3.3. Classifying hand gestures

In the real world, the hand gestures that we use for (dis)assembly and maintenance tasks are various. The use of hand gestures can be classified and summarized depending on different situations [17]. In this research, we focus on the appropriate hand gestures to use in maintenance tasks. Any maintenance work of mechanical products involves disassembling and assembling mechanical parts as well as mechanical joints. To simplify the classification, we grouped the various existing mechanical joints into four types of temporary joints; screw, nut, bolt, as well as snap fit and tabs. In order to understand the even greater variety of hand gestures, we defined three types of screws; Hex Lag Screws, Sheet Metal Screws and Wood Screws. As for the nut, we defined two types; Hex Head Bolts and Socket Cap Screws. For the bolt we defined two types; Hex Finish Nuts and Wing Nuts. Snap fit and tabs is a rather complex task in a virtual environment. Therefore, we defined only one example from disassembling plastic box as show in Fig. 5.

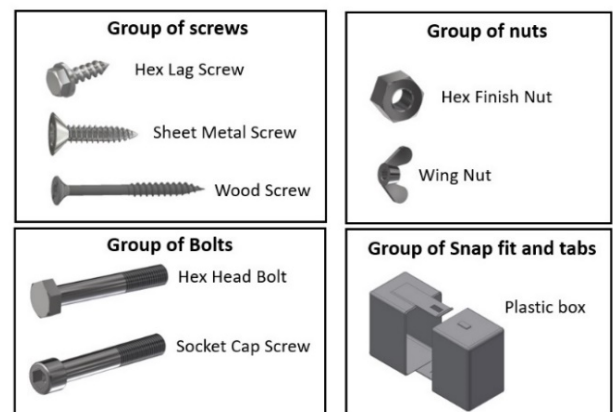


Fig. 5. Type abstraction of mechanical joints.



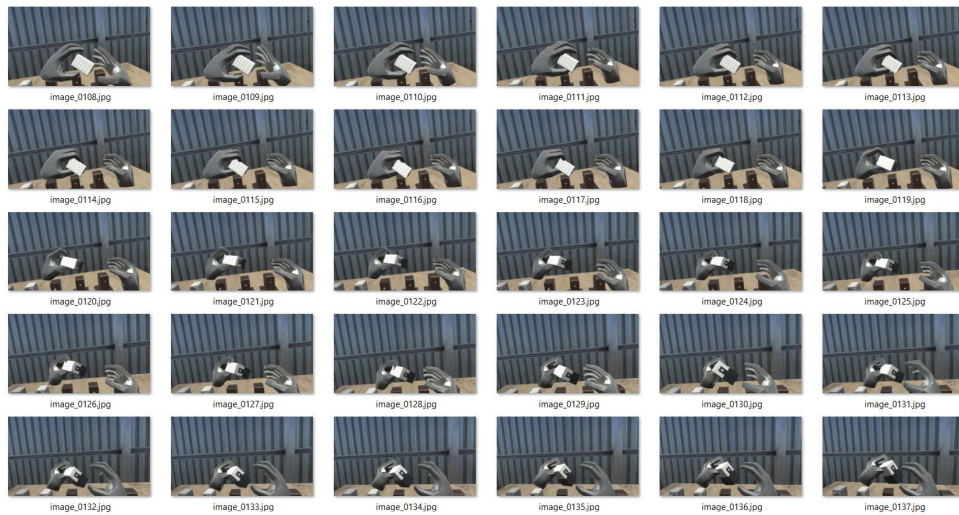


Fig. 6. Recording an image sequence.

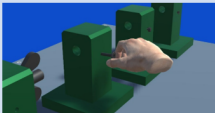
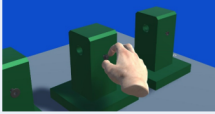
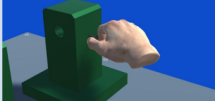
Type of maintenance task	Pattern of hand gesture	Definition	Hand gesture
Removing Sheet Metal Screws	Pinch with TI1 T = Thumb I1 = Side of Index	This hand gesture use Thumb and side of Index to pinch the screw and rotate the screw to left or right. This hand gesture will use with the small head of screw and round head screw.	
Removing Hex Lag Screws	Pinch with TI2 T = Thumb I2 = End of Index	This hand gesture use Thumb and End of Index to pinch the screw and rotate the screw to left or right. This hand gesture will use with the hexagonal screws and square screws.	
Removing Wood Screws	Pinch with TI1 T = Thumb I1 = Side of Index	This hand gesture use Thumb and side of Index to pinch the screw and rotate the screw to left or right. This hand gesture will use with the small head of screw and round head screw.	

Fig. 7. Pattern of hand gesture using with screws.



Type of maintenance task	Pattern of hand gesture	Definition	Hand gesture
Removing Hex Finish Nuts out from Hex Head Bolts	Pinch with TIM T = Thumb I = Index M = Middle	This hand gesture use three fingers to catch the bolt and nut. Thumb, Index and Middle will be used to catch the head of bolt and nut. Using three fingers is easy used to catch and rotate.	
Removing Wing Nuts out from Socket Cap Screws	Pinch with TIMP T = Thumb I = Index M = Middle P = Ring	This hand gesture is a special type, it use four fingers to catch the wing nut (Thumb, Index, middle and Ring). Thumb and Middle use to pinch the middle of head of wing nut. Index and Ring use to control upper wing and lower wing because it will use to rotate clockwise or counterclockwise.	

Fig. 8. Pattern of hand gesture using with bolts and nuts.

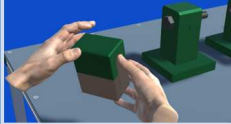
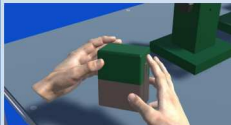
Type of maintenance task	Pattern of hand gesture	Definition	Hand gesture
Removing plastic part by snap fit technique	Unwrap and pull with Thumb	Using thumb to unwrap and pull the plastic slightly out from locking. Then, take off one of them out together.	
	Unwrap and pull with Index	Using index to unwrap and pull the plastic slightly out from locking. Then, take off one of them out together.	

Fig. 9. Pattern of hand gesture in term of snap fit technique.

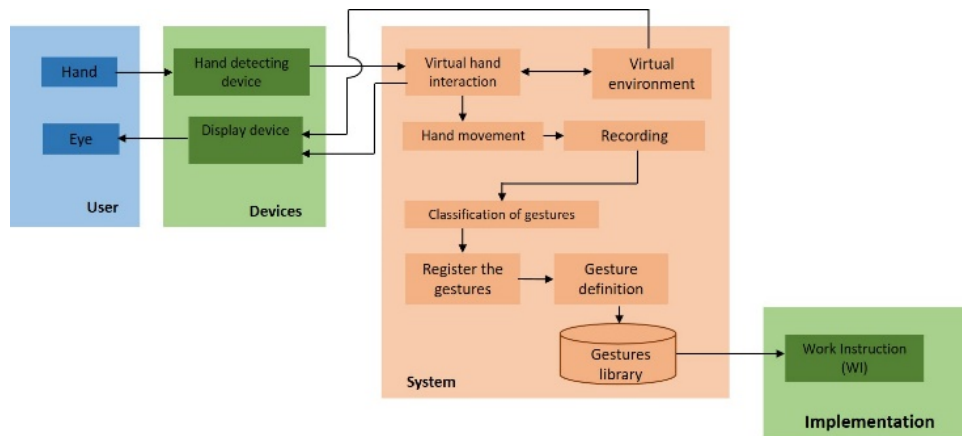


Fig. 10. Technical framework for the gesture recording process.

### 3.4. Executing and recording hand gestures

In this process step, various experts were asked to practice in VR platform. While they were doing so, we observed and recorded their hand gestures with the picture recording function as 30 frames per second and an image resolution of 720 pixels as shown in Fig. 6. The virtual camera is set in the first person perspective corresponding to the real human eyes' position.

The experiment started with the process of disassembling of Hex Head Bolts and Hex Finish Nuts then, Socket Cap Screws with Wing Nuts. The removing process of Hex Lag Screws, Sheet Metal Screws and Wood Screws out from the wooden pedestal will be next step. As the final step, plastic box will be performed by snap fit technique.

### 3.5. Specifying hand gestures as patterns

In this step, we analyzed the experts' recorded hand gestures focusing on the appropriate ones for being able to add them to work instructions later. We defined patterns of hand gesture based on postures of the hand and the fingers used, then we explained the definition for those gestures as shown in Fig. 7, 8 and 9.

### 3.6. Building a library of hand gestures

Building a library of classified hand gestures is the fundamental step towards being able to systematically associate mechanical joint types, required expert gestures and appropriate VR device configurations. Initially, we stored those gestures in the format of doc and pdf, since the gestures that we registered for demonstration are not numerous. In the future, however, we plan developing a system for recording, specifying and storing gestures with a mostly automated system based on Machine Learning.

To implement such a library, we created the technical framework that is shown in Fig. 10. It connects the user, VR devices, as well as the components required for the gesture classification. It ultimately leads to the Implementation step dedicated to the preparation of the work instruction.

As the system framework shows, users are involved in the virtual reality environment through their eyes and hands. A VR device is used to track the movement of the real hands, and the virtual hands are re-constructed in the virtual environment accordingly. Thereby, the expert users become a central part of the process of recording and visual gesture specification. By recording scenes from several different experts and/or the same experts carrying out procedures a number of times in the same or different ways, the system can build up a knowledge base of gestures applied to categories of joints. This knowledge base can subsequently be used in combination with machine learning algorithms to train the system in suggesting appropriate gestures given a particular assembly.

## 4. Virtual Reality framework for gesture experimentation

Within the virtual environment, we created the framework that we used to experiment with hand gestures applied to the mechanical joint models as shown in Fig. 11. We input the function of rigid body, mesh render and mesh collider to all of the 3D objects, while the function of interaction behavior we input only for the objects that we needed to manipulate. We divided the anchor function into two types: anchor object and anchor base. The anchor object is used for attaching to the anchor base when the object moves near the anchor base, while anchor base used to define the position.

This framework of relationships allows us integrating the joint-specific movement requirements and constraints in the virtual environment with reasonable effort. It is generic and allows easy extension of both the scene and the assemblies to manipulate.

## 5. Discussion and conclusion

In this research, we propose an approach to recording, classifying and clustering such hand gestures of maintenance tasks in a library of gestures. In this library, we can characterize each gesture and relate them to mechanical assembly and disassembly operations with respect to their appropriateness. The motivation for doing so is rooted in the need to create work instructions that shall illustrate details of

hand gestures that are the appropriate for particular maintenance operations. Embedding this approach in an environment for maintenance training preparation in a VR environment, we also presented the method for creating a digital knowledge base of maintenance hand gestures using virtual technology. The connection between users, VR devices and the recording system have been designed according to a generic framework of the gesture recording process. Although users still lack haptic perception for practicing in this environment, they can see and use their bare hands to work in the virtual environment without any danger of breaking anything or even getting injured.

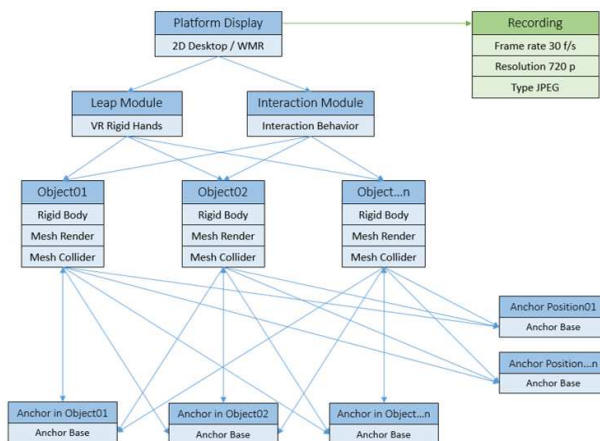


Fig. 11. The framework of anchor object and anchor base.

This work is part of a bigger research project that aims at establishing an integrated VR environment for preparing, evaluating, and executing maintenance trainings in virtual environments. The sustainability interest of transferring such training and assessment tasks is obvious in particular for the maintenance of huge, stationary, locally fixed installations that are globally distributed. The evaluation of the efficiency and effectiveness of our approach will be evaluated once all the elements of this environment and the underlying VR-TPP concept will be available.

## 6. Future work

Based on this initial proof of concept, we plan further extending the gesture library by more types of mechanical joints. We will investigate various ways of exploiting this library for the creation of work instructions and training plans, as well as the validation of the correctness of gestures during virtual trainings. In order to implement haptic perception, we plan integrating the CyberGlove into our platform. We also expect that using CyberGlove will allow recording the hand gestures more accurately and clearly. We will also integrate the work instructions generated from the gesture library as virtual work instructions (VWI) in the VR environment. Furthermore, we will develop the concept that we use in this demonstration to be standard. Which can be create from standard or special platform. In this standard, we can apply to other work. Especially, assembly and disassembly work.

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