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## VIRTUAL REALITY TRAINING SYSTEM BASED ON 3D SCANNED AUTOMOTIVE PARTS

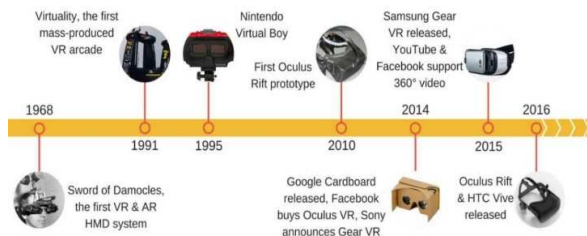
Radu COMES, Călin NEAMȚU, Anca GRAJDEANU, Stefan BODI

**Abstract:** The paper proposes a workflow methodology to obtain accurate 3D models optimized for various virtual reality training environment. The case study within the paper is focused on automotive mechanics training with specific scenarios focused on component recognition and assembly. The virtual reality application has been developed in Unity 3D and it enables users to experience the immersive virtual reality environment with a wide variety of Head Mount Display setups from various manufacturers. The 3D models used within the environment have been obtained using structured light scanning technologies applied on real components to ensure that the 3D models are accurate replicas of the real components both in terms of geometrical dimensions as well as visual properties. The proposed virtual reality system represents an upgraded version of the usual human-machine training system by enabling users to have access to detailed 3D models directly in an immersive virtual reality environment therefore replacing the need to have the available material resources available locally at the training facility as physical parts, assemblies and equipment which require warehousing and specific manipulation and logistics.

**Key words:** virtual reality, 3D scanning, training system, automotive,

### 1. INTRODUCTION

Virtual reality technologies have evolved at a rapid pace during the last years, this is mainly due to well established tech companies who have made the effort to create headsets with a truly immersive presence while keeping the overall cost of the VR system to enable mass adoption [1]. Ten years ago, the only viable truly immersive VR system costs several thousands of dollars and used various CAVE systems or other layouts with multiple wall projections to enable immersive virtual reality presence [2].



**Fig. 1.** The evolution of VR systems until the mass adoption of VR HMD systems in 2016 (Oculus Rift & HTC Vive) [1]

The main uses of virtual reality environment since their early prototypes have been focused on two major direction which are: training in various domains [3][4][5] and entertainment [6]. The human perception of what is real is closely tied with the inputs provided by our senses (sight, hearing, smell, etc.) which are interpreted by the brain. Virtual reality systems can be used to tailor these senses enabling various digital experiences for their users, thus creating the effect of an interactive three-dimensional environment where objects have a sense of spatial presence and spatial properties. Virtual reality technologies have started to be used as an effective tool in the automotive industry allowing the development teams to better visualize the car concepts and their components adding value to various automotive development design phases [7].

The automotive industry has been one of the early adopters of 3D scanning technologies in various production phases. Some 3D scanning solution have been successfully used to transfer clay models to accurate CAD models to serve as 3D mesh references for Class A surfaces while

other 3D scanners are suitable to be used in production to inspect complex shapes [8] in real-time. Combining 3D scanning with virtual reality enables the further development of smart manufacturing and training [9].

## 2. VR SYSTEM DESCRIPTION AND METHODOLOGY

### 2.1 VR system architecture

The proposed virtual reality system consists of multiple HMD devices linked to an application created in Unity 3D enabling multiple users to experience the same environment in real time while having the possibility to see the other users and their controllers within the digital environment. Single user virtual reality application used for automotive mechanics training have been developed by other researchers [10] or companies [11]. There are companies that have developed multiuser virtual reality environment such as Autodesk VRED [12] or Dassault Experience 3D [13] that are compatible with HMD VR Headsets but these are professional software solutions that are not free, plus they do not provide customization such as 3D applications created with Unity 3D. Other researchers have also proposed a multi-user VR system used for Training [14].

Our training application has been tested on multiple setups. The most powerful setup used to test the application was an intel i9-9900k workstation paired with an Nvidia Geforce GTX 2080 GPU paired to Valve Index VR. Another VR system used the HTC Cosmos HMD paired to an i7 laptop with a mobile version Geforce GTX 1070 GPU. The same mobile workstation has also been linked to HTC Vive Pro with a wireless module to provide better VR mobility.

### 2.2 Methodology

The most important element of a virtual reality application is represented by the 3D models used within the digital environment. For the virtual reality application presented within this research the first step was to 3D scan various automotive components to obtain accurate 3D models of components available on the market.

The methodology used to transfer the 3D scanned files to the VR application has the following four phases:

- Phase 1 – 3D scan of real components
- Phase 2 – 3D Mesh to CAD
- Phase 3 – CAD to \*.fbx
- Phase 4 - \*.fbx to VR application

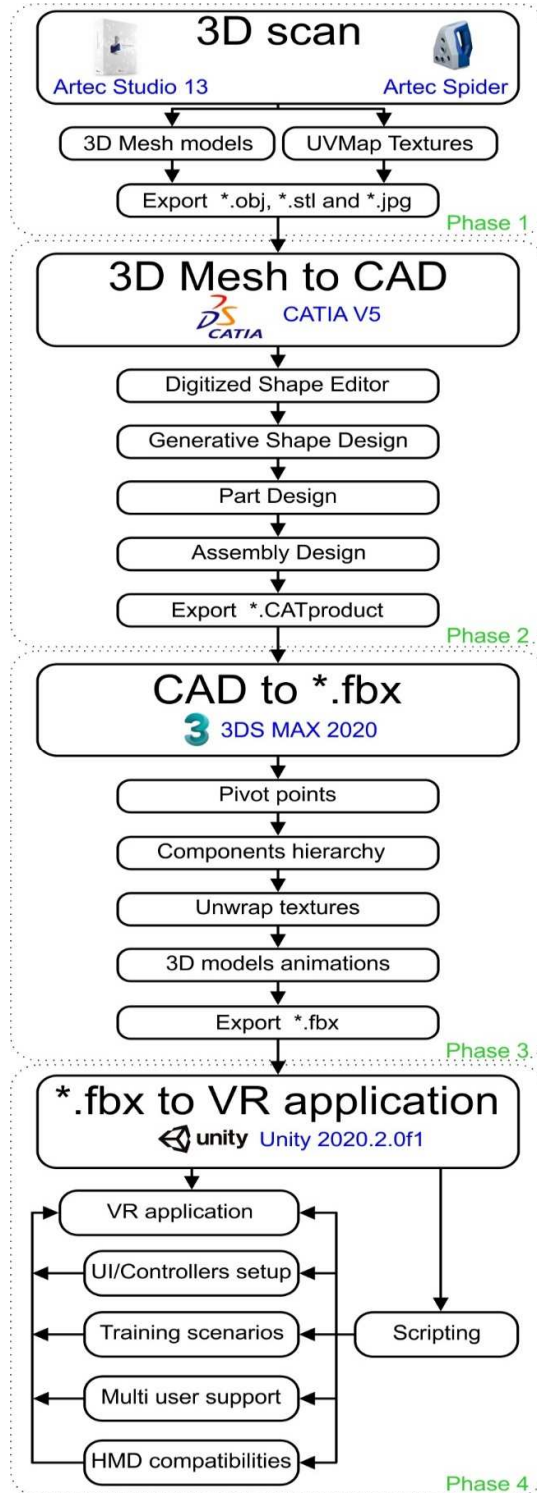


Fig. 2. 3D scan to VR application methodology

There are various challenges regarding the file transfer of both 3D scanned models and CAD model to VR applications. The main challenge is to obtain accurate 3D models and have them in virtual environment compatible file format. 3D scanned models contain a high number of vertices linked together to define the mesh of the model. In comparison CAD models generated by computer aided design software are defined by Non-uniform rational B-splines. Both file formats are not suitable for VR and require additional file format conversion.

The proposed methodology requires multiple software solution to ensure the 3D scan processing and file conversion is defined within a certain deviation tolerance.

The raw data sets have been imported to Catia V5 to ensure the 3D scan to CAD conversion. For the CAD file conversion and animation, the educational version of 3ds Max 2020 has been used. The virtual reality environment has been developed using the educational version of Unity3D – version 2020.2.0f1.

### 2.3 Phase 1 - 3D scan of real components

To validate the proposed methodology described within this paper, a series of case studies have been deployed on various car components.

In one case study, the components of a car front suspension (Fig. 3) have been disassembled and 3D scanned individually.

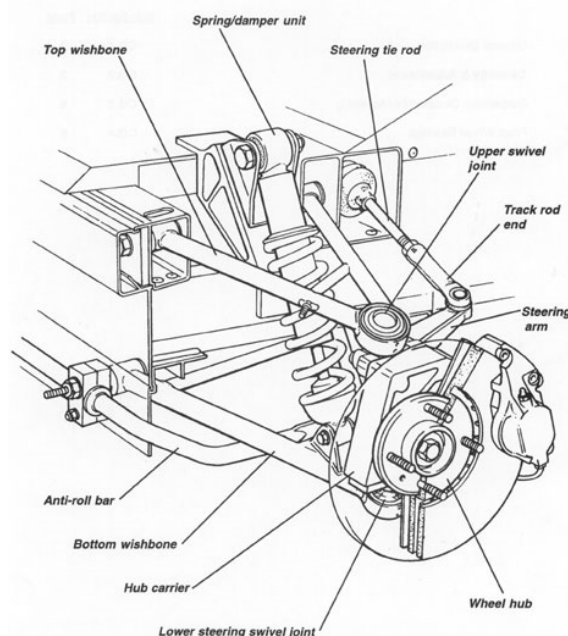


Fig. 3. Front suspension parts

Each component has been positioned on a rotative table and 3D scanned with the Artec Spider scanner [15]. They were repositioned on the turning table to ensure that the part is fully scanned. Some detailed parts required additional reposition on the turning table to capture all the features and details. The Artec Spider structured light scanner has been chosen over other 3D scanning solutions available within the Technical University of Cluj-Napoca Measurement and 3D scanning laboratory [15] since it can 3D scan objects with sharp edges thin ribs and various intricate details.

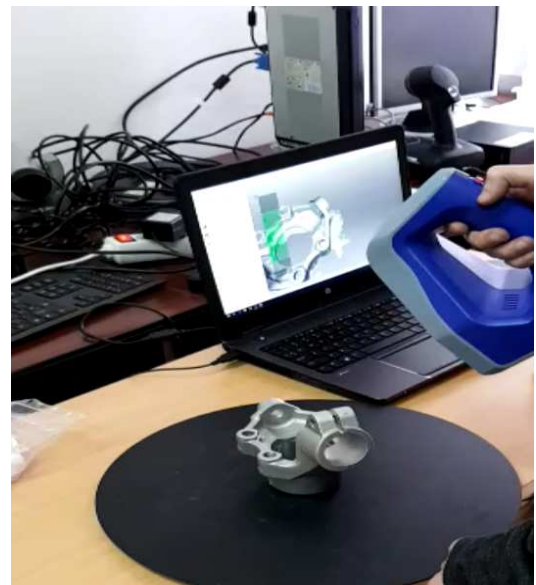


Fig. 4. 3D structured light scanning of the steering knuckle

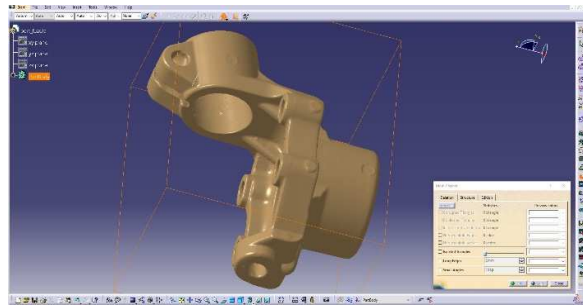
The 3D scanned datasets have been exported in \*.obj and \*.stl file format for the 3D geometry, having the individual XYZ coordinates for each vertex. The texture has been exported in \*.jpg file format with the associated UVMap path of the \*.obj file linked with the \*.mtl file.

The software solution Artec Studio 13 enables multiple 3D scans to be aligned thus obtaining individual 3D detailed models for each component by trimming the support elements such as the turning table geometry.

### 2.3 Phase 2 - 3D Mesh to CAD

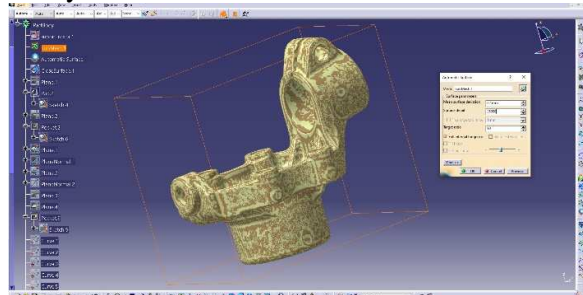
The process of transforming 3D scanned meshes to CAD models involves the use of multiple workbench modules within Catia V5.

The case study of Phase 2 is illustrated on a steering knuckle. This is the component that contains the wheel hub and is attached to both the suspension and other steering components. The first step is to import the \*.stl file format in Catia V5 – Digitized Shape Editor workbench and process the scanned 3D mesh to ensure that there are no corrupted triangles, duplicated triangles, inconsistent operation, non-manifold edges, non-manifold vertices, etc. It is also important to make sure that within the structure tab of the Mesh Cleaner feature that the model is not split in more than one distinct connected zone during this phase. The mesh can be joined if there are more than one distinct connected zone within the same workbench.



**Fig. 5.** *Catia V5 – Mesh cleaner feature of the 3D scanned steering knuckle*

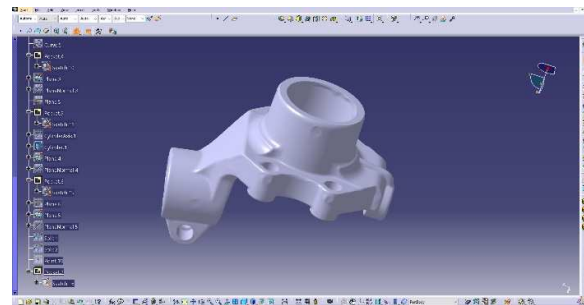
With the 3D scanned mesh cleaned, the next step involved the conversion of the 3D mesh to a surface model, this process can be done automatically within the Quick Surface Reconstruction Workbench within Catia V5. For this component, the surface parameters were generated using a 0.1 mm mean surface deviation and a target ratio of 90 while maintaining the full internal tangency of the newly define surface.



**Fig. 6.** *Catia V5 – Quick Surface Reconstruction of the steering knuckle (colored in yellow) overlapping the initial 3D scanned mesh (colored in brown)*

The output of this step is presented in Figure 6, the initial mesh is colored with brown while the newly generated NURBS surface is colored in yellow. As it is highlighted within Figure 6 the two surfaces are overlapping in most of the areas while the whole surface is contained within the 0.1 mm mean deviation.

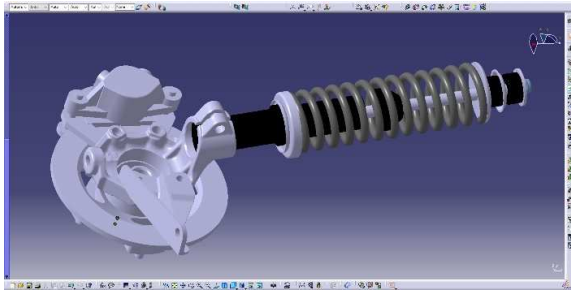
Having the exterior surface of the steering knuckle defined as a NURBS surface, the surface can be converted to a Part Design element within Catia V5 using the Close surface feature. This will enable the 3D model to be filled with material enabling finite element and kinematical analysis which are specific to computer aided engineering. For virtual reality it not mandatory to obtain filled components since the models will be further exported and lose this property. But for application when you want to define section cuts within the virtual reality training process this step can enable accurate section within components and assemblies.



**Fig. 7.** *Catia V5 – Closed Surface – Part Design component*

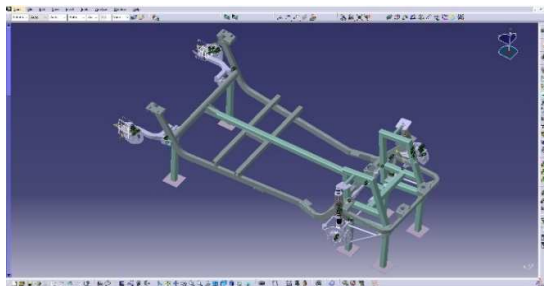
For the final assembly of the car suspension, it is important to obtain the CAD assembly file to ensure that the parts are correctly assembled using the required assembly mate features. This step can be recreated within 3ds Max latter without any problems but having the components positioned and constraint directly within the CAD software enable a better fitting of the parts for the virtual reality application. The most important position the final correct assembly position where individual parts will be scripted to snap in position. The assembly of the front left car suspension is illustrated below.





**Fig. 8.** *Catia V5 – Final assembly of the left front car suspension*

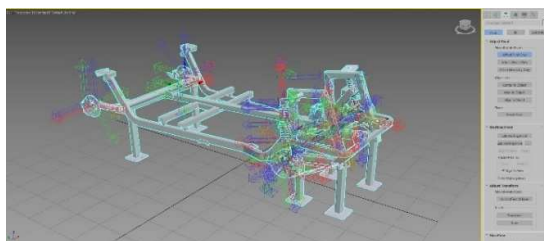
As a case study scenario for the virtual reality training application for automotive mechanics, a custom frame which holds all four car suspension assemblies has been designed. To have the whole assembly correctly assembled, within CATIA V5 Assembly Design workbench, all the elements have been constrained using computer aided design features such as coincidence, contact and angle constraint. The final constrained assembly is illustrated in Figure 9.



**Fig. 9.** *Catia V5 – Constrained car suspension assembly*

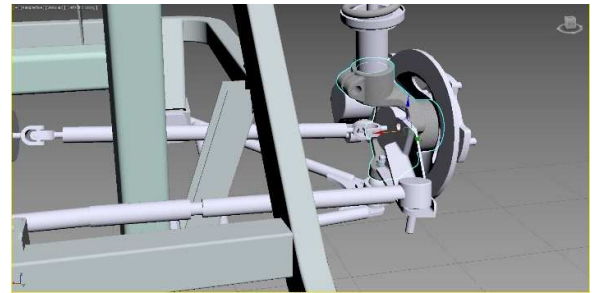
### 2.4 Phase 3 – CAD to \*.fbx

For the next phase, the workflow will be done entirely in 3ds Max. Having the 3D CAD model loaded in 3ds Max the first step is to realign the pivot points of each individual component and then define the components hierarchy. This step is highlighted in Figure. 10



**Fig. 10.** *3ds Max Pivot defining the points and components hierarchy*

To keep the visual aspects as close to the real components it is important to define the textures of each components. The textures can be extracted from the initial 3D scan if the scanner supported texture acquisition, or they can be recreated using pictures of the real objects. The textured generated using Artec Spider which has only a 1.3 MP sensor can be further processed to increase the overall resolution by merging the initial textures acquired by the scanner with digital images acquired using a DSLR camera



**Fig. 11.** *3ds Max applying textures to the 3D models*

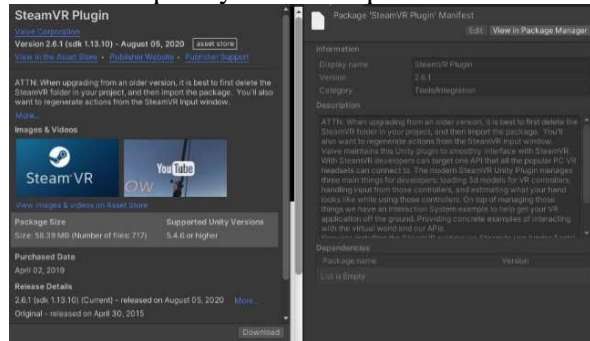
The last step of this phase is to generate the desired animations. This step can be done directly in Unity, but for predefined animations such as exploded view and assembly of the components this step can be animated directly in 3ds Max and exported as an \*.fbx file with the baked animation for each frame. This workflow is one of the most widely used to combine 3D modeling software with game engine, there are other alternatives both in workflows and software options.

### 2.5 Phase 4 – \*.fbx to VR application

The last phase of the methodology is focused on applying various scripts within Unity to define the virtual reality application. Having the parts prepared in 3ds Max as \*.fbx will ensure a smooth import towards Unity and these elements will be used as prefabs to quickly generate the virtual environment. This is the phase that requires the most time to be developed in order to define custom scenarios with individual steps and milestones that the user need to follow in order to complete his virtual reality training. The following section will highlight the most important development steps of the virtual reality training application.

### 3. THE VIRTUAL REALITY ENVIRONMENT

The virtual reality environment within Unity has been defined using the Steam VR Plugin sdk 1.13.10 from The Asset Store. This toolkit has been developed by Valve Corporation.



*Fig. 12. SteamVR Plugin in Unity asset store*

The virtual reality training application has been created using features within this toolkit such as the teleporting function, the object grabbing and various UI elements. The VR Plugin enables the customization of the Controllers, when paired with the latest Valve Index controllers, they can be used to track individual fingers of the user. In this case the user hands will be generated in the virtual reality environment using some predefined 3D hands.

To define various training scenarios custom scripts were created to define step by step assembly instructions as the one illustrated in Figure 13 where multiple components are positioned on a table in front of the user, each one has a naming label on top and to the right of the table there is an assembly area where the user must drag the individual component to fulfill the assembly training procedure.



*Fig. 13. Step by step assembly*

A custom user interface with multiple buttons has been defined within the virtual environment. The custom buttons enable various automated assemblies that the user can follow to understand the correct assembly position of each component. Figure.14.



*Fig. 14. Custom buttons positioned within the virtual reality training environment*

The user interface and controller setup has been customized for each user (teacher and trainee), the teacher has the possibility to grab 3D models from the trainee virtual hands and they can communicate using external microphones so that the teacher can provide real time correction and feedback to the trainee.

### 4. CONCLUSIONS

Combining 3D scanning with virtual reality technologies enables the rapid development of accurate 3D models that can be used for training and instruction. By repeating the training scenarios multiple times, the users improve their knowledge and reduce the time required to assemble correctly various components.

The developed virtual reality environment can be used to recreate a wide variety of training scenarios from various fields.

The main advantage of using virtual reality application for training and instruction is that 3D scanned models can replace real objects thus eliminating the need to have the components and equipment physically available to enroll the training procedure.

The main drawback of the proposed workflow is that all the digital elements need to be generated in 3D (either by 3D scanning or modelling) and then require additional time to script the desired training scenarios.

The application has been tested by various students, they have adjusted rapidly to the virtual reality environment and understood the controllers input functionalities. They had no problems to manipulate the 3D components and complete the training scenarios regarding automotive mechanics components.

## 5. ACKNOWLEDGMENT

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## SISTEM DE INSTRUIRE ÎN REALITATE VIRTUALĂ BAZAT PE PIESE SCANATE 3D

**Rezumat:** Lucrarea propune un mediu de realitate virtuală care poate oferi mecanicilor auto recunoașterea individuală a pieselor și asamblarea corectă a diferitelor componente. Aplicația de realitate virtuală a fost dezvoltată în Unity 3D și permite mai multor utilizatori să experimenteze mediul de realitate virtuală captivant cu o mare varietate de configurații de afișare montate pe cap. Modelele 3D utilizate în mediu au fost obținute folosind tehnologii de scanare 3D a pieselor din viața reală pentru a se asigura că modelele sunt replici exacte ale componentelor reale atât în ceea ce privește dimensiunile geometrice, cât și textura. Rezultatele experimentale obținute au evidențiat eficiența sistemului atunci când un utilizator experimentat se alătură aplicației de realitate virtuală și îndrumă utilizatorii de instruire pentru a identifica, prelua și asambla diferite componente auto. Sistemul propus reprezintă o versiune actualizată a sistemului obișnuit de instruire om-mașină, permițând utilizatorilor multipli să se alătore aceluiși mediu și să efectueze instruirea direct în realitate virtuală, optimizând astfel nevoia de a avea resursele materiale fizice disponibile local pentru instruire (piese, ansambluri, echipamente etc.)

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