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COBEM-2017-5511 VIRTUAL ENVIRONMENT TO PART ASSEMBLY USING DISPLACEMENT COORDINATES

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Abstract: In recent years many virtual reality applications have contributed to the physical realization of mechanical products. In this line, this article reports the first steps of the parts mechanical assembly virtual environment development. It is intended to be used in the product development process in which prototypes must be tested in their concepts and ways in the search for alternative solutions for quality improvement. The accomplishment of this process implies the verification of layout and the adequate positioning of parts in the product assemblies, besides its correct manipulation, calibration and optimization of geometric and dimensional tolerances. At the beginning of the research, the goal was to create a collision detection model to make the assembly process more real to user observation in the immersive virtual environment. There was no time for this development. It was then decided to create in the virtual assembly model subdivided with the two-stage assembly process, nominal assembly and adjustments assembly. In the nominal assembly the parts are positioned in the virtual environment from the definition of the six coordinates of linear and angular displacement of their center of mass (CM) previously created in the solid modeling in the CAD software, ie, x , y , z and $\alpha(x)$, $\beta(y)$, $\gamma(z)$, respectively. In the second step, the fine adjustment is made, in which the user performs positioning at a slower speed, from a manual Joystick control, making the constraints associated with the dimensional and geometric tolerances previously defined for each part in the phase of detailed product design. The virtual assembly environment consists of a room that contains a mounting table and a cabinet in which are stored the parts to be assembled. The user immerses in the virtual environment through the RIFT oculus where it interacts with the assembly process and commands the movement of the moving parts to the final assembly position. While attempting to create a collision detection model between parts that could better target parts during the virtual assembly process, it was not possible to complete its development. It is expected that in the near future this model can be used in future works.

Keywords: *parts virtual assembly, displacements coordinates, virtual reality assembly.*

1. INTRODUCTION

The theme definition and its scope began from the vision of the needs demanded by the industry and the academy. In industry, assembly processes have greatly increased the product final cost when they do not have simulation aspects and previous checks involved. Also, in teaching engineering, it is necessary to visualize the assembly processes so that they can be studied with criteria and better definition in the product development process detailed design phase, taking into account the parts positioning and form aspects, besides the use tools correctly and without affecting ergonomically mounting procedures. It was understood that a virtual environment in which the user can manipulate the parts and observe the assembly variables as dimensions and geometric tolerances and have control over them, is a favorable resource to the product development process improvement as a whole.

At this point, a plan of this research was elaborated: mechanical project virtual assembly process overview, collision detection in virtual reality overview, mechanical assembly without parts collisions detection, optimization of the software and hardware resources definition and available for the development, training in previously defined software and hardware, search for alternative solutions to the parts collisions detection problem in the assembly, change of focus from assembly research with collisions to assemblies guided by linear and angular displacement coordinates, dimensional and geometric tolerances for be considered in the virtual assembly, geometric and dimensional tolerances adjustment in the assembly, case study to implement the results of the virtual assembly environment, problems listing to be solved and conclusions.

2. THE MECHANICAL DESIGN VIRTUAL ASSEMBLY PROCESS OVERVIEW

The use of VR in engineering design applications can lead to greater credibility in the systematic checks required to the product design process steps and in the other product lifecycle stages as long as the virtual applications do not disregard the environment such as pressure, gravity, temperature, among others. This must be taken into account, especially when such requirements are fundamental to the product dynamic behavior. For assembly procedures verification, performed with criteria and design requirements during the preliminary and/or detailed design phases, ie, before the product is manufactured, the VR technology can be used progressively as needed design tasks, dynamic simulation, static, assembly/disassembly simulation, manufacturing process simulation, assembly process and others. Still, in an academic view, it brings with it infinite possibilities of applications in teaching in all knowledge areas. In engineering courses, its applications have grown considerably and, in mechanical engineering, specifically, it grows in the stride, supported by industrial applications where it has been developed strongly, mainly in the automotive industry, aerospace and oceanic (Kim and Vance, 2004), (Aziz, *et al*, 2015).

In this way, as an auxiliary design tool, it allows the project team to achieve a higher level of security in their decisions in a shorter time, which cooperates to achieve the product desired quality. In applications that use VR with a high level of hardware and software, it is possible to carry out all the assembly process, to check parts layout or to manufacture and assembly, without losing the actual assembly details and requirements, to the point that there are no differences between the which is real and virtual, such as materials characteristics such as density, weight, inertia, mechanical properties in general (Muhanna, 2015), (Tuma, *et al*, 2014).

There are several good virtual simulation commercial programs, but they require objects movements programming and people in a given simulation language, generating the simulation results in an immersive environment. The true power of VR lies in the application interactivity and changes in the system due to user participation. This requires a very high level of physical models modeling and simulation (Clark and Moodley, 2016), (Lawson, *et al*, 2016). (Tuma, *et al*, 2014)

The engineer and/or product designer, in the various knowledge areas in which the design step is necessary, be it engineering, design, architecture, computer science, among others, has in large part, the need to meet various design requirements, defined for the product in the design process initial phases, specifically in the informational design phase, according to the methodology that systematizes the four-phase design process (Jayaran, *et al*, 2001).

In the definition phase of function tree solution principles (Clark and Moodley, 2016), (Linhares, 2005) derived from design requirements, the designer does not yet have the appropriate tools to assist him in his design intentions. He usually defines them from the search for alternative solutions through searches in bibliographic sources, area solutions databases and also through his experience in the field of action. Alternative solution databases usually provide solutions that do not meet the requirements as a whole, since each project has its momentary particularities.

It is natural that the material collision between parts, in a real assembly, is often intuitively performed. However, it is necessary to know the functions of each part so that no mistakes are made of assembly, which happens in great quantity in the industry, causing losses in production, especially when it comes to serial manufacture. For example, in virtual assembly, there is a need to have a system that provides this important capability in the assembly operation, that is, scripts that provide the inability of the parts to cross one another without collision. This is the key problem of this research, the collision between parts during the virtual assembly process. The collision facilitates interlocking of parts, avoids geometry contradictions in directing assembly actions, makes assembly quicker and will enhance the use of the application both in the academy and in the training of industrial assembly operations.

The collisions problem ecomes in this point of the research a great obstacle to its continuity since the objective is that the user proceed to the parts assembly during the design process to verify inconsistencies related to the geometric form of the assembly parts details, its positioning and orientation and the verification of dimensional and geometric tolerances defined in the CAD project documentation (Zachmann, 2000), (SOLIDWORKS, 2017), (Melnikoval, 2015).

From now on, the research will be focused on finding alternative solutions to the collision detection problem between the assembly parts. Thus, in the case study, whose components served to arrive at this conclusion, the parts are assembled no longer with collision detection, but with the provision of position and orientation coordinates, three displacements (x, y, z) and three rotations $\alpha(x), \beta(y), \gamma(z)$. Based on the each part final positions coordinates, it is possible to carry out the respective assemblies considering design geometric and dimensional tolerances between the parts. The main parts reference are their pivots, here defined as their respective mass centers (MC).

3. VIRTUAL REALITY OVERVIEW

Virtual Reality, as an emerging technology, has been helping the development of countless other technologies in the last years, impacting the quality and the products and services development time. Throughout this trajectory many works have been published and contribute to new developments in the area. Related to the proposal developed and described in this article, several references should be commented on, making a brief retrospect of what was actually used in its elaboration. In mechanical engineering, in the product design process, Virtual Reality (VR) is a new way of presenting information to the designer so that it can interact in real time with future activities within the designing

activity and, mainly, in the manufacturing and Assembly. The key elements of this new architecture are (a) Immersion in a 3D environment through stereoscopic visualization; (B) Sensitivity of presence in the environment through user tracking and often representing the user in the environment; (C) Presentation of information about other senses besides vision (audio, haptic = touch sensation, smell, among others), and (d) Realistic behavior of all objects in the virtual environment. In this way, advanced hardware and software technologies have come together to enable the creation of successful VR applications. Engineers have been using CAD systems for decades to model and analyze their designs. CAD systems have matured significantly in the last decade with the parameterization and solid 3D modeling skills for surface composition using NURBS (Non Uniform Rational Basis Spline) and also through triangulated polygonal structures (Jayaran, *et al*, 2000b).

VR systems are unlikely to replace CAD systems as a daily tool used by designers in the near future. However, VR systems demonstrate utility in product design, in the shape requirements evaluation, function (Clark and Moodley, 2016), fabrication and assembly, in three-dimensional environment. Thus, the appropriate integration between CAD and VR systems is essential for the success of applications in the industry.

VR systems are still mostly extensions of computer graphics programs. CAD modelers generate solids from triangulated NURBS and polygons defined geometries generating significant engineering data losses when converted within VR applications and their conversions. Triangulated models, for example, fail to make the approximations of dimensional and geometric tolerances required for design analysis, fabrication, and assembly/disassembly. Thus, any clearance check, for example, performed using the display model, is very superficial. The significant challenge in this area is the creation of an appropriate virtual prototype data model for VR applications (Bordegoni, *et al*, 2006). In order for VR technology to become a mechanical design tool, it is necessary for CAD systems to either develop virtual reality in their solid modeling modules, or today's virtual reality systems develop 3D modeling capabilities with the requirements imposed by engineering Mechanical, which are not few.

The traditional interface of a mechanical design work environment consists of monitor, mouse and keyboard. Virtual reality technology allows a more natural interaction with computers, which is achieved by allowing a person to use natural movements, for example, pointing, picking, gesturing, and others, which provide input data to the computer. The computer provides a true and realistic three-dimensional graphical display to the user and a sense of presence or immersion in the virtual, computer generated environment. This interaction level is achieved through a software and specialized hardware combination that supports such applications.

Applications in virtual reality engineering focused on providing methods for three-dimensional input and stereoscopic visualization. However, in the last five years, several advanced applications have changed the perspective of engineers in the product development process. These applications range from conceptual design tools to manufacturing simulation tools and maintenance assistance tools. Many of these applications have been placed with varying degrees of success by industry (Bordegoni, *et al*, 2006).

The typical design process today involves computer modeling followed by the construction of physical prototypes to check the digital models. Since virtual reality offers a three-dimensional design possibility in which the user interacts with computer images three-dimensional in a natural way and still using VR technology as a prototyping tool, it becomes a very promising opportunity. For example, solution alternatives to the realization of a project can be examined in reduced time if they existed purely in digital form as compared to the physical and expensive prototypes construction and testing. There are many design decisions that must be made before a product enters the manufacture. Virtual reality makes a significant difference in design evaluations, and especially in the relation of design engineers to the design product process. Using only the traditional computer interface consisting of monitor, mouse and keyboard, users are prevented from interacting with digital product designs. The use of a virtual reality interface makes it possible for the designer to move closer to interacting with the digital design as if it were a real object (Lawson, *et al*, 2016).

In the preliminary design phase in which the project must be analyzed from the point of view of static and dynamic requests, it is possible to mechanical components forms and geometries optimize. Virtual reality presents a unique interface for interpreting analysis data. It can be used as a general post-processing tool for commercial finite element analysis codes such as FEA. The first VR application in engineering was the Virtual Wind Tunnel or NASA Virtual Wind Tunnel. The works of, Bryson and Levit (1992), Ryken and Vance (2000) and Yeh and Vance (1998a) present a virtual environment for evaluating the finite element analysis application results. In addition to investigating stress contours, the application provides the ability to change the part shape and examine the resulting changes in stresses (Jayaram and Vance, 2001). Using this tool, analysts can interactively determine where to change the shape to reduce stress before attempting a complete finite elements analysis. Using a combination of NURBS geometric modeling techniques and finite element sensitivities (Yeh and Vance, 1998a, 1998b, 1998c), the user can reach the virtual environment, change the product shape, and interactively examine changes in product stresses (Yeh and Vance, 1997), (Perles and Vance, 1999). Once a suitable design is obtained, a complete finite element analysis is performed to obtain the actual stresses.

Another very promising application of virtual reality is in the area of virtual manufacturing, assembly and disassembly. Once again the focus is on reducing the physical prototypes number needed to provide an environment for the digital models evaluation. Often, in product design, most of the product geometry is finalized without assembly/disassembly process evaluation needed to manufacture the product. However, ineffective assembling methods

come out very expensive once they have been verified over the time stipulated for the design process. A means for production engineers to participate early in the design process where design changes are less costly will lead to products that can be more efficiently used, retained, reused, recycled, and assembled within the pre-set need of the product life cycle user (Jayaram, *et al*, 1999), (Srinivasan, *et al*, 1999).

In the works of Jayaram, *et al* (1999), Connacher, *et al* (1996), Wang, *et al*, (1999), Jayaram, *et al* (2000), developed a virtual assembly application called VADE (Virtual Assembly Design Environment) in partnership with the US National Institute of Standards and Technology (NIST). VADE is an advanced tool for assembly processes evaluation and immersive planning. Methods have been created to automatically transfer CAD models of assemblies, subassemblies, and parts to the VADE environment. Translated data includes geometry, mass properties, inertia properties, assembly hierarchy, and assembly constraints.

In the immersion environment, the user can perform two-handed assay evaluations by manipulating the base part with a controlled hand and picking up other parts with a gloved hand. The geometry constraints used to assemble the parts in the CAD system are extracted and used in the immersive environment to guide the user. This helps to preserve the design intent of the assembly between design and manufacturing (Jayaram, *et al*, 1999).

The capabilities of VADE also include collision detection, swept volume creation and editing, swept type (common operation in 3D geometric modeling systems), parametric modifications in the immersive environment with automatic data transfer to the CAD system, tools and templates a real environment. VADE has been used successfully in several studies using models from the truck, engine, machine tool and construction equipment industries (Jayaram, *et al*, 1999).

Srinivasan *et al* (1999), have developed assembly and disassembly in three-dimensional or Three Dimensional Assembly and Disassembly (A3D), which focuses on digital pre-assembly analysis. This involves the generation, editing, validation and animation of assembly / disassembly sequences, assembly routes, cost and time for 3D geometric models. A3D maintains a hierarchical assembly structure and allows the user to add constraints, edit the overall shape of the component, and calculate the resulting sequence, routes, cost, and time in a virtual environment.

In a semi-automated way, the user can generate complex sequences and component routes and validate the resulting assembly/disassembly operation. In addition, the user can perform various other virtual manufacturing reviews, such as interference checking, clearance verification, component accessibility analysis, and design rule verification. The A3D is built using the ACIS and PARASOLID geometry cores. In addition, you can analyze assembly models in PARASOLID, SAT, IGES, SAT, STL, DXF, OBJ and VRML formats. To facilitate virtual maintenance analysis, efficient algorithms for selective disassembly of one or more components were developed and incorporated into the A3D system (Srinivasan, 1999a, 1999b). The designer can also make design changes to facilitate disassembly for maintenance (Srinivasan, 1999b, 1998). Other works in the virtual assembly area include virtual disassembly for product life cycle analysis (Siddique, 1996), virtual assembly in BMW (Dai, 1999) and virtual assembly using game machine (Aziz, *et al*, 2015).

4. MECHANICAL ASSEMBLY WITHOUT PARTS COLLISIONS

In the actual assembly, the parts are positioned to perform the functions for which they were designed, meeting the geometric and dimensional tolerances required and specified by the current Technical Standards. This technology allows the designer to verify dimensional and geometric tolerances and seek to improve the performance of functions parts and assembly as a whole in an interactive way, for example, by interacting with dynamic simulations in devices with relative movement between fixed and moving parts or between moving parts. In this research, only the position and shape geometric tolerances are considered. Form tolerances have a special impact on manufacturing processes, while position tolerances, ie, angularity (direction), position/spacing and concentricity (location), have a particular impact on the assembly process.

At this point, collision detection between parts in the virtual assembly environment is required. This problem was discussed ostensibly in the literature review, section 3, and here it is concluded as it was decided to postpone its development to be a near future, in the second stage of this research, since it was not possible in due time to create a model of collisions to give the user the feeling of contact between the pieces and also for their physical orientation in the virtual assembly environment. Although it has reached an environment where parts are available for assembly, collision detection between parts is an unresolved problem and at this point in the research, it has changed its direction and ultimate goal.

4.1 Dimensional and geometric tolerances in the virtual assembly

One of the parts must be initially positioned, the base part which should remain positioned relative to the assembly table local reference system and will no longer move until the end of the assembly, thus having linear and angular positioning coordinates zeroed. Each piece will have its restrictive tolerances, geometric and dimensional, associated with the base part and the part(s) with which it has a direct functional interface. The pieces take their tolerances for assembly, especially when interacting sequentially in the input and output functional interfaces. There is a tolerance thread to be considered which must be pre-calculated before the final assembly is performed (Umaras, 2010). The

concept of "static/dynamic behavior in use" is reinforced here, where each part in an assembly acts through interfaces with one or more parts, either statically or dynamically. All parts of an assembly have somehow direct/indirect functional interfaces with the others. However, only a few have direct interface with functions that form considerable functional chaining that imply static/dynamic behavior when in use.

The part functions are associated with their dimensional and geometric tolerances forming a tolerance and functional chain. The behavior in use of the parts in an assembly is a theme to be developed with a view to be realized in virtual reality environment in the near future together with the technology of dynamic simulation by CFD-type finite elements and dynamic structural simulation. The geometric and dimensional tolerances/restrictions will be programmed in this project via script in the UNITY® software itself and will be controlled by the user, that is, the user sets their values in specific fields in the virtual environment. This means that you can, for example, change the linear deviations minimum and maximum limits between the any two pieces symmetry axes, $[+0,50; -0,75]^{min}$ para $[+1,25; -0,25]^{max}$ (mm).

Likewise for the angular deviations minimum and maximum limits between the any two pieces symmetry axes, eg from $[+ 30,75^\circ; -0,50^\circ]^{min}$ para $[+ 0,45^\circ; -1,50^\circ]^{max}$. Before handling a part, the user must configure its mounting tolerances, otherwise the part will not leave the cabinet. After setting its tolerances (dimensional and geometric), the assembly will be carried out to its functional position by commands based on the coordinates of final positioning. The dimensional and geometric tolerance configurations programming shall take into account the geometric tolerances shown in Table 1 and their equivalents and respective numerical values of dimensional tolerances, as shown in Table 2.

Table 1 shows the classification of geometric tolerances pointing in gray color to those that are considered in this research, one related to the direction and two related location, according to the nomenclature used by ISO. In the virtual environment modeled in this research a tolerance specifications table, as shown in Table 2, receives the numerical values corresponding to the linear and angular displacements allowed for each part in the assembly and their respective dimensional and geometric tolerances corresponding to the values specified in the sheets mechanical drawings.

Table 1 – Geometric tolerances classification (Fischer, 2008).

geometric tolerances(*)		
	position	form
direction	parallelism	linearity
	perpendicularity	planicity
	angularity	circularity
location	position (displacement)	cylindricity
	concentricity	linear shape
	symmetry	superficial form

(*) Position tolerances type Course and Total Course not are considered in this study.

The dimensional tolerances considered here follow ISO (Normas ISO, 2017) for measurements, limits and adjustments, as shown in (Fischer, 2008). They will be obeyed through the values described in the automatic tolerance adjustment tables in the virtual environment. The geometric tolerances are classified as shown in (Fischer, 2008). However, although this classification shows the shape and position tolerances, the position tolerances of the Course and Total Course type will not be considered here. It was noticed that all types of position and shape tolerances can be adjusted by varying the linear and angular displacements values proposed in this work.

Table 2 – Input dimensional tolerances(**) values examples and associated geometric tolerances.

displacement	variable	part 1			part 2			geom. tolerance associated
		coord.	máx.	mix.	coord.	máx.	mix.	
linear (mm)	x	540,00	0,01	0,01	32,00	-0,005	+0,002	concentricity
	y	1000,00	0,01	0,01	-45,00	-0,075	+0,025	symmetry
	z	-280,00	0,01	0,01	347,00	-0,005	+0,002	concentricity
angular (°)	$\alpha(x)$	0,000	0,005	0,005	0,000	0,005	0,005	parallelism
	$\beta(y)$	0,000	0,005	0,005	0,000	0,005	0,005	parallelism
	$\gamma(z)$	0,000	0,005	0,005	0,000	0,005	0,005	parallelism

(**) part dimensional tolerance: allowable variations for each nominal dimension.

4.2 Knowledge about functions before virtual assembly

The user must have previous knowledge of the mechanical engineering area and know the meaning of the tolerance and adjustments read in the sheets of mechanical drawings to be able to pass the values previously specified in Table 2 that receives the numerical values corresponding to the correct assembly.

It is also necessary for the user to know the device functional structure, the each global, partial and elemental levels part functions of each part detail. A functional structure example is shown in Figure 2. In addition, you must know the function-shape relationships of the geometries created in the part. Dimensional tolerances are treated here by numerical values of predefined positions or deviations, eg, [50,00 (+0,50 and -0,75)] (mm), which means a tolerable dimensional range between 49,25 mm and 50,50 mm. These tolerances can be referenced between the part and the world reference system, in the case of tolerance chaining between two parts and between more than two parts in the assembly as a whole, in relation to the assembly itself reference system, and between the assembly and the virtual environment reference system. The geometric tolerances such as Concentricity, Parallelism, Symmetry, Planicity, and others, are evaluated relatively between parts and between parts and the assembly as a whole in the VR environment.

Ulrich, (2008), presents values for geometric adjustments and tolerances of shape and position in tables placing appropriate values for both geometric and dimensional tolerances. This research considers geometric tolerances of direction, a tolerance of angularity, and geometric tolerances of location, such as position/distance tolerances and concentricity.

5. CASE STUDY FOR IMPLEMENTING THE VIRTUAL ASSEMBLY ENVIRONMENT

A case study is carried out using 3D geometric models previously created in internal works within the Engineering Faculty of the University of Porto (FEUP). The case study is implemented in the Laboratory of Virtual Reality (LabRV) of the Mechanical Engineering Course of FEUP (LabRV), using as development platforms the software described in Table 3.

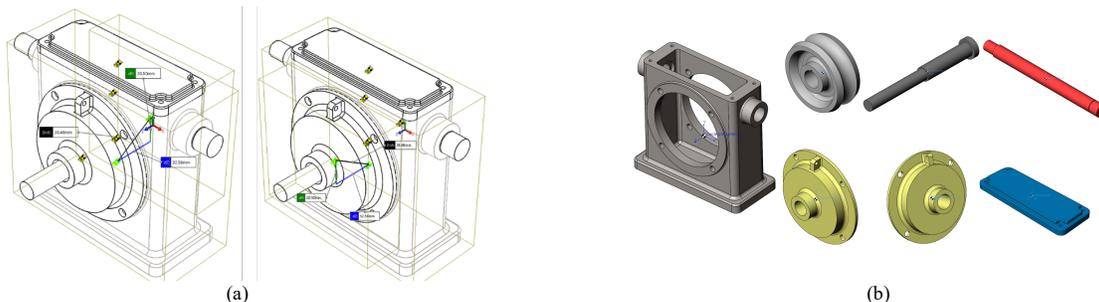


Figure 1 – (a) Gearbox showing the linear displacement coordinates between base and flange1 and flange2 mass centers as shown in Table 3 and (b) Parts that make up the case study gearbox, (modeled in SolidWorks®).

5.1 Gearbox functional structure

Gear reducer functional structure graphical representation is shown in Figure 1(b) and the each function description shown in the sequence. The parts considered are called: base, crown, shaft1, shaft2, flange1, flange2 and cap.

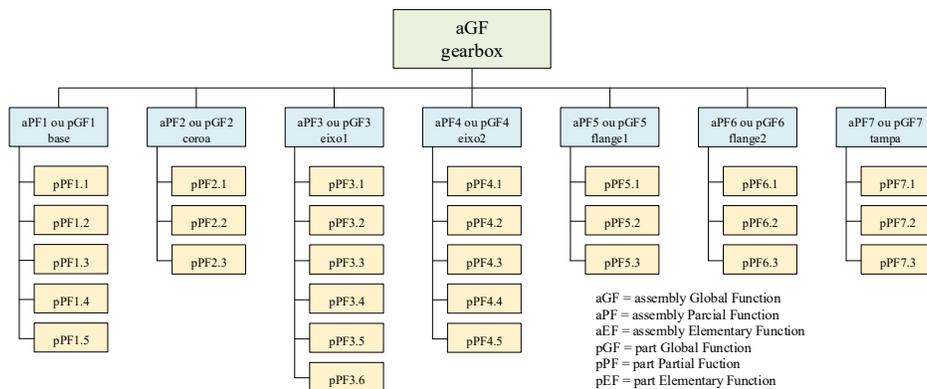


Figure 2 – Gear reducer functional structure graphical representation.

The device used in the case study is called a gearbox, shown in Figure 1(a) and has the overall function of "Transmit torque and power with reduced speed". It is a speed reducer with end screw. To perform this global function, the device is composed of several parts that aggregate mechanical functions of input and output with functional interfaces that as

shown in the following study. From the speed reducer, modeled in SolidWorks®, were highlighted 7 (seven) parts: base, crown, shaft1, shaft2, flange1 flange2 and cap. The parts are shown in Figure 1(b).

5.2 Software and hardware resources

As previously reviewed, there are many commercially available hardware and software features that are currently geared toward building virtual reality systems. Some alternatives to creating free-access games are also available, including UNITY® version 5.5.1f1 and Blender version 2.78a, used here to create the projects in the search whose scenes are used in the virtual reality environment of the parts assembly application. As a resource available in the laboratory, in addition to the aforementioned softwares, LabRV has the following input, operation and output devices for the development of VR technologies: RIFT DK2 óculus; Leap Motin Controller (LMC); Rods NANUK 910; PPTX2 Cameras; Speakers LogiTech; Projector Panasonic; gloves 5DK; ECRAM 3,5x1,8m²; PC^s embedded and physical space with a volume of 8,0x5,0x2,80(m³). Totally, the devices used in the research for the virtual reality system (VR) implementation are with shown in Table 3.

Table 3 – Hardwares and softwares used in research.

Hardwares	RIFT: VR immersion goggles; LMC: Leap Motion Controller; PC: Personal Computer; NB: Notebook particular; Joystick: ThrustMaster Analog4
Softwares	UNITY®; SolidWorks®; Blender®; Vizard®; MSVisio; MSPowerPoint

UNITY® aggregates inbound and outbound settings and converses with other applications through the C^{Sharp} language. Blender® (the Blender Foundation), a free open source 3D modeling platform suitable for three-dimensional modeling that requires animation, rendering, simulation and interface with Virtual Reality applications and which includes Python scripting language and SolidWorks® allows modeling components by providing the templates in extensions that are converted to extensions appropriate to the virtual environment.

In order to create the solid 3D models, he used CAD software SolidWorks® version 2016-2017, licensed to the Product Development and Services Laboratory (LDPS) of the Mechanical Engineering Department (DEMec) of the Faculty of of the Porto University Engineering Faculty (FEUP). Once created in SolidWorks®, the solid part models used in the sample assembly are saved in the (.stl) extension within SolidWorks itself and then opened in Blender. Import the (.stl) template that is converted back and saved with (.fbx) extension, which can be read in UNITY®.

5.3 Assembly guided by linear and angular displacement coordinates

After verifying the need to detect collisions between the parts to be assembled in the process of virtual immersive assembly and to have reached the conclusion that for this research a collision model could not be developed in a timely manner, it was decided to develop the assembly by positioning coordinates means using the linear and angular displacement variables inherited from the parts mass centers created in SolidWorks®, as shown in Figure 1(a). The assembly shown in Figure 1(a) is composed of 7 (seven) parts. In the figure, each assembly part displays the its respective mass center symbol. The base part has coordinates $(0,0,0)$ and $(\theta^o, \theta^o, \theta^o)$, system origin in which all other parts linear and angular displacement coordinates, are referenced. Figure 3 shows in (a), the virtual gearbox mounting environment on the UNITY® interface as the user sees and can interact in the case study, before assembling and, in (b), the gearbox after its Assembly.

It is assumed that for the creation of a virtual assembly the solid models and their assembly were previously created in the CAD software, that is, the mass centers (MC) of each part and also of the assembly are defined before being imported into the system. virtual reality. When the first part (base part) is positioned in the mounting environment in the CAD system, a reference system, a assembly three-dimensional reference system, is created.

In the CAD system, all the parts that make up the assembly, including the base part, have their three-dimensional coordinates defined when inserted into the assembly and their coordinates are given by the positions or distances x, y, z (position vector) of their mass center, as shown in Figure 1(a), where we can observe the all parts mass centers positions of the assembly that highlights fields with the displacements coordinates x, y, z values and the resulting position vector (Dist :) in red, green, blue and black fields, respectively. The mass center symbols appear in light green color. The mass center is a property inherited by the solid model when created in SolidWorks® (SOLIDWORKS, 2017). In an assembly it is necessary to have a part that serves as a reference, such as a mounting base.

The reference coordinates values are shown in Table 3. Thus, all parts can be assembled with reference to their respective position vectors, since the part position vector is the distance between its mass center and the base part nmass center. The mass center is a material point that exhibits 6 (six) specific coordinates, three of linear positioning (linear displacement) and three of angular orientation (angular displacement). To make the adjustments that correspond to the thresholds or deviations of each measure, the user is based on values tables, as shown in Table 4. The values

tables are configured in such a way that when the values are reached, the part changes of color, going from red to green, which means that it will be mounted.

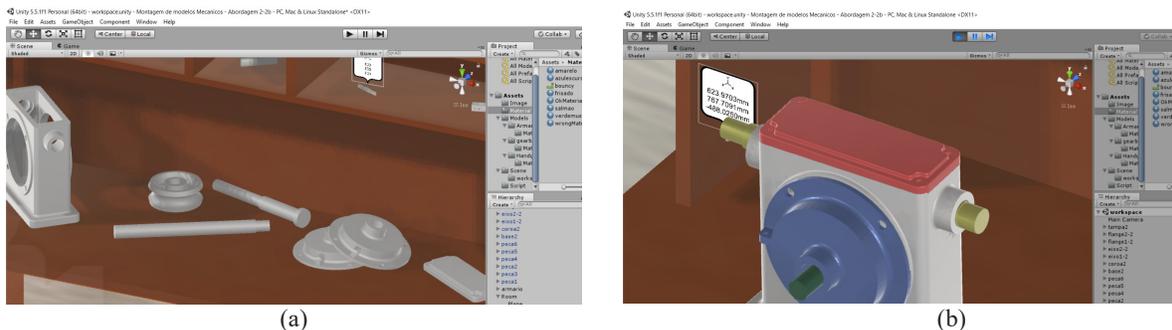


Figure 3 – UNITY® interface image showing the virtual parts assembly environment for the gearbox.

In the nominal assembly, the parts are automatically positioned in the mounting position from *Joysitck* commands having as positional coordinates the mass center linear and angular displacements defined in the solid 3D CAD model, as shown in Table 4. In the adjustment assembly, a tolerances table is shown to the user who moves each part through the controls, *Joysitck* buttons, in which the parts movement speed in the respective translation and rotation axes is reduced, so that the user can have the appropriate sensitivity to the required adjustments by checking the values corresponding to the dimensional and geometric tolerances designed for each two-parts coupling.

Table 4 – Mass centers coordinates of the parts assembly shown in Figure 1(a).

part	mass centers coordinates (MC)						position vector
	linear position (mm)			angular position (graus)			
	x	y	z	$\alpha(x)$	$\beta(y)$	$\gamma(z)$	$dist (mm)$
1 – base	0,00	0,00	0,00	000,00	000,00	000,00	0,00
2 – crown	0,00	20,23	0,00	000,00	000,00	000,00	20,23
3 – shaft1	0,00	20,24	0,91	000,00	000,00	000,00	20,26
4 – shaft2	- 4,14	54,53	0,00	000,00	000,00	000,00	54,69
5 – flange1	0,00	20,50	- 32,56	000,00	000,00	000,00	38,48
6 – flange2	0,00	20,50	32,56	000,00	000,00	000,00	38,48
7 – cap	0,00	78,96	0,00	000,00	000,00	000,00	78,96

The values referring to the adjustments limits (dimensional and geometric tolerances) are shown in Table 5. The user must be free to choose the adjustment speed that best suits him to make the fine adjustments of each tolerance until reaching the each part assembly final position. This should be able to be adjusted.

Table 5 – Linear and angular displacements limits of the gearbox parts assembly.

displacements coordinates	values allowable ranges in the assembly (nominal value \pm indicated values)														
	base		crown		shaft1		shaft2		flange 1		flange2		cap		
limits	máx	mín	máx	mín	máx	mín	máx	mín	máx	mín	máx	mín	máx	mín	
linear (mm)	x	0,00	0,00	0,05	-0,01	0,075	-0,025	0,075	-0,025	0,05	0,05	0,05	0,05	0,05	0,05
	y	0,00	0,00	0,05	-0,01	0,075	-0,025	0,075	-0,025	0,00	0,00	0,00	0,00	0,00	0,00
	z	0,00	0,00	0,05	-0,01	0,025	-0,025	0,025	-0,025	0,05	0,05	0,05	0,05	0,05	0,05
angular (graus)	$\alpha(x)$	0,00	0,00	0,50	-0,50	0,25	-0,25	0,25	-0,25	0,25	-0,25	0,25	-0,25	0,25	-0,25
	$\beta(y)$	0,00	0,00	0,50	-0,50	0,25	-0,25	0,25	-0,25	0,25	-0,25	0,25	-0,25	0,25	-0,25
	$\gamma(z)$	0,00	0,00	0,50	-0,50	0,25	-0,25	0,25	-0,25	0,25	-0,25	0,25	-0,25	0,25	-0,25

When the position vector coordinate values of all the parts mass centers forming the assembly are passed to the position and orientation coordinate table, shown in Table 4, the assembly positions and orientation are defined and the assembly with adjustments can be performed in the virtual assembly environment from the input commands for each part given by *Joysitck*. The coordinate axes crossing in each part, the world reference system and the final assembly, are called here "pivots". The pivot world reference system is fixed while the part and assembly pivots are movable and located in their respective mass centers (MC).

The part movement from its initial position to the final position in the assembly is done with the aid of the six available displacement movements, three of translation and three of rotation. The translation displacements are called (x, y, z) , respectively, related to the linear displacements in the directions defined by each coordinate axis. The rotational displacements around each coordinate axis are called, respectively, $\alpha(x)$, $\beta(y)$, $\gamma(z)$. All shifts can be performed from the commands defined on the *Joystick*, alone or together, in two or three directions, simultaneously. Each offset has its speed set in the script that *Joystick* commands. Figure 4 shows the *Joystick* used with the displacement control commands. Three other pushbuttons control shifting of parts, from translation to rotation (T/R), and from normal (fast) to slow shift speeds. To perform the virtual assembly process, some devices were created and inserted. In the case of small mechanical assemblies this is usually done on a support table. Therefore it was understood that a support table and a cabinet where the parts are stored, is the most appropriate set to the virtual environment to the virtual assembly. In order to carry out the assembly, a relation between three three-dimensional reference systems was created: a main, fixed to the assembly table, each of the local part reference system to be assembled and positioned in the respective mass center (MC), and a third, localized in the final assembly.



Figure 4 – Angular and linear (Translational motion or Rotation – T/R) displacements control system, Joystick.

After the part positioning in the location defined by the values described in the assembly coordinate table, the final positioning can be done by means of the values corresponding to the tolerances required. The tolerances defined in the manufacturing and assembly drawings are transferred to the tolerance tables that depict the dimensional and geometric tolerances considered.

6. CONCLUSIONS

Virtual reality technology has developed to the point where serious engineering applications have begun to be implemented by industry around the world. However, not all engineering applications are suitable for immersive environments. The immersive environments provide significant benefits to the processes that require the movements and actions in which the operators are people. These systems are also very valuable in reducing the number of physical prototypes required during product development, enabling the creation of product virtual scale-real prototypes and the product manufacturing process.

The problems resolution pointed out previously depends much more on software than hardware, in the case of this research. The proposed application development team should have at least two programmers in C^{Sharp} language, preferably engineering, where possible, mechanical engineering. It is necessary that the researcher of the knowledge area in which the assembly must be done pass on to the programmers the operations really necessary to the immersive environment and when they must be carried out. The main problem is configuring the collision detection effect between parts. It is necessary for the user to have the feeling, at least in the visual sense, that the parts collide with each other and exhibit stiffness during handling so that they can be assembled.

The behavior in use of the interfaces between parts, that is, input and output interfaces, leads to the functions chaining knowledge which justify the bold modern mechanics design, whose full realization determines the product quality. Knowing the way dimensional and geometric tolerances affect assembly between parts is also crucial for the virtual assembly system user to master the assembly finalization before any simulation kind, whether static or dynamic, is required.

In the case of this research, the detection collisions problem must be solved, before which nothing can be added in terms of verifying the parts behavior in the virtual assembly process. So a next goal is to solve it. Moreover, not only is the list of problems presented above a future realization focus, there are still the part gravity and rigidity problems which are equally and simultaneously to be solved in the near future.

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8. RESPONSIBILITY NOTICE

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