Training for Bus Bodywork in Virtual Reality Environments

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Abstract. This document presents a virtual training system oriented for learning of electric welding applied to automotive body assembly industry. The training tasks are developed in a virtual immersion environment created with Unity 3D graphic software, in order to improve the user's skills and welding skills through a teaching-learning process that allows the virtual manipulation of industrial instruments. In this way, the experience in welding task is obtained, risks of industrial accidents are reduced and waste is eliminated. The experimental results show the behavior of the system and the evolution of the user's skills.

Keywords: Electric welding · Virtual reality · Bodyworks assembly

1 Introduction

Virtual reality is a world created in computer, where the user has the feeling of being internal in this one. The applications of this tool grow with great expectation due to the creation of immersion technologies, such as Oculus Rift, HTC, Leap Motion, etc. The same ones that allow to increase the sensation of realism and the interaction with the virtual environment [1]. In recent years, virtual reality applied to learning allows to develop significant and necessary skills to act in real processes, simplifying the training of professionals in diverse areas where learning activities have a certain level of risk in case of not performing correctly, in [2] it is shown that the fidelity of the immersion is a feature of great relevance which involves the realism of the input devices and their interaction, the fidelity of the screen or output devices and finally the loyalty of the stage that corresponds to the realism of the environment simulated [3]. Currently, virtual reality is involved in several areas and allows the development of several applications such as *(i) Medical,* for physical rehabilitation systems, surgical training for surgeries, [4]; *(ii) Psychologists,* in applications relating to social interaction training for people with autism, [5]; *(iii) Entertainment*, such as the development of motion platforms for video game immersion, [6]; *(iv) Education,* focused on technology with virtual reality for education, [7]; *(v) Industry,* training in a technical environment regarding risk prevention and various industrial maintenance techniques, [8].

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Currently, virtual reality training in the industry allows technical operators to train safely as they can manipulate protection elements and industrial equipment, as well as the visualization of technical diagrams facilitating the understanding of the process and the connections related in it, as explains in the work presented in [9]. In the work described in [10], it affirms this idea when proposing a welding training system that allows feedback to identify patterns of wrong movements for correction, thus optimizing training by improving welding quality and reducing production times, very important data in the metallurgical industry [11], of infrastructures [12] and automotive [13].

For this reason the virtual reality within the automotive engineering has become a main tool that through cooperation with software of design of mechanical components of vehicles, simplifies many procedures such as the schematization and creation of basic parts in the construction of vehicles such as is exposed in [14], the development of virtual laboratories allows research associated with the need to observe safety measures within the manufacture of vehicles as well as the use of equipment used in the training of engineers as it is an economical alternative [7], In this way, construction work is provided that demonstrates a high level of reliability in each piece that makes up the automotive [15].

Considering the above, this work presents in a first instance the simulation in virtual reality of a bus assembly plant which allows the immersion of an individual with the aim of strengthening the recognition of automotive assembly processes, in addition in second instance, the user is virtually trained in electric welding tasks, specifically in the main joints of the metallic body, which is coupled and assembled on the common chassis existing in the ecuadorian market.

Therefore, the presentation of this document is structured as follows: the parameters of the electric welding is exposed in Sect. 2, the development of the structure of the virtual reality system described in Sect. 3, the virtualization of the electric welding process is explained in part IV and finally the Analysis of Results in the Sect. 6 with their respective conclusions defined in Sect. 7.

2 Parameters of Electric Welding

Electric welding is one of the most common tools in the construction of metal structures, because it represents an accessible instrument whose quality depends exclusively on the skills and experience of the welder, who through a series of factors can determine a good appearance. The drawback of this practice is that such skill is only obtained with experience, generating waste of resources, also the demand by industry requires trained employees to ensure quality work with the elements available in the plant. Likewise, good industrial safety and quality management practices promote a good work environment suited to the needs of each process [16]. Here is the correct use of protections, such as gloves, mask, glasses, as well as the correct selection of electrodes and current intensity to perform this work.

In this work we propose the development of a virtual application where the user is able to develop physical and psychological skills with the advantage of reducing waste in a virtual environment where their physical integrity is not exposed to risks in case of mistakes, optimizing time work and increasing production.

The welding training procedure starts with: *(i) Electrode,* the correct selection of the electrode dependent on the material to be welded, such as galvanized iron, carbon steel, A36 steel, etc. *(ii) Position,* where refers to the type of orientation of the weld either vertical or horizontal; *(iii) Machine,* in the practical case an AC welding machine is presented. For the selection of the electrode, its numbering must be recognized: this code allows knowing the parameters *i, ii,* and *iii* mentioned above, this depends on the quality of the weld that depends on the resistance exerted by the welding per square inch, therefore, for the selection of the electrode to be used, Table 1, standardized by the AWS, is used. (Society American Welding) for the selection of its penultimate number [17].

Table 1. Classification of the penultimate number according to AWS

Classification AWS	Coating	Welding position	Electric current
E 6010	High cellulose, sodium	F, V, OH, H	CC (+)
⋮	⋮	⋮	⋮
E 7018	Under hydrogen, potassium, iron powder	F, V, OH, H	CA ó CC (+)

Where, according to the AWS standards, the welding positions are: F: flat; H: horizontal; H_Filete: horizontal fillet; V_Descending: vertical descending; V: vertical; OH: ceiling or overhead. In the same way the currents for each electrode are: AC: Alternating current; CC (+): Positive polarized direct current; CC (−): Negative polarized DC current. From this selection it is obtained that the electrode to be used must have 1 as the penultimate number because it allows welding in any position and also the use of the alternating welding machine which is used in the virtual environment.

For the selection of the last number of the electrode, the Table 2 of the last number of electrodes exposed in the AWS standard is taken as a basis [17].

Table 2. Classification of the last number according to AWS standards

Last digit	Current	Cladding	Arc type	Penetration
E XX11	CA ó CCPI Reverse polarity	Organic	Strong	Deep
⋮	⋮	⋮	⋮	⋮
E XX18	CA ó CCPI Reverse polarity	Low hydrogen	Medium	Median

In this way it is determined that the electrode suitable for the practice of body welding would be the electrode: E_7018.

Once the electrode to be used is established, the current necessary to be applied by the machine is identified, the wrong current is selected, faults that damage the welded material are produced. Also, when applying too low an amperage, the weld bead will not be uniform and the electrode will stick in the weld. While if the amperage is very high there is a lot of splashing and the piece to be welded will be perforated. The amperage needed to perform the electrical welding is within a set range with values that can be identified in the electrode's datasheet or it can be found analytically using the formula 1

$$I = (\phi - 1) * 50 \quad (1)$$

where: I is the intensity; ϕ is the diameter of the electrode. As shown in Fig. 1 of amperage limits of an electrode in this case for a diameter of 3.25 its optimum amperage is calculated as follows:

$$I = (3.25 - 1) * 50$$
$$I = 112.5\,[A] \cong 110\,[A]$$

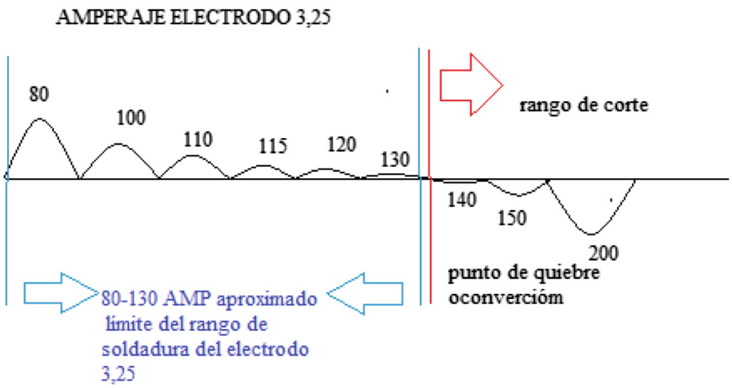


Fig. 1. Amperage limits for an electrode 3, 25

Once the electrode is established and the level of intensity to be used, the time in which the heat must be applied to the solder is established. For this purpose, the heat transfer equation presented below in formula 2 is determined:

$$Q = R * I^2 * t \quad (2)$$

where Q is energy in the form of heat expressed in Joules; R resistance in ohms; I intensity applied in amperes; t time in seconds. For the correct welding of a material it is necessary to follow steps and essential parameters that are commonly performed empirically producing waste of both economic resources and raw materials, for this reason the development of a virtual training environment gives us the possibility to develop the skill needed to perform this task correctly.

3 Structure in Virtual Reality

The proposed application is developed in the Unity 3D engine for graphics with the aim of associating the virtual assembly and welding operations with the input and output devices which allow to interact with the process as shown in Fig. 2. The application uses the Steam VR plugin able to use the controls and interact with simple instructions.

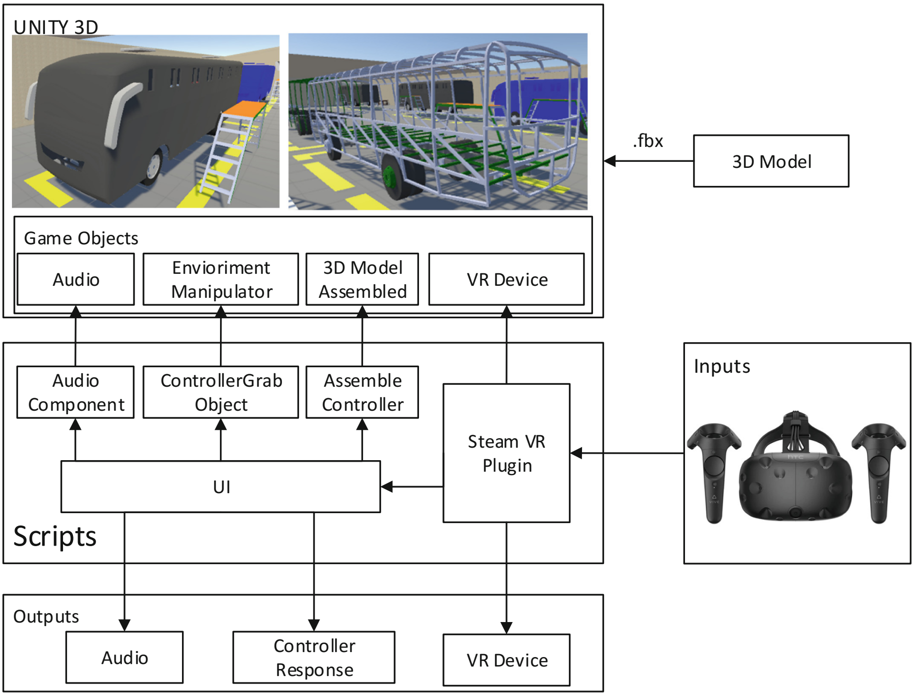


Fig. 2. Components diagram

Virtual reality programming is performed for the simulation stage of each work scenario, where the components of the bodywork and the assembly controller are linked, in this phase is the respective configuration of physical properties, coupling and welding of parts that simulates a realistic assembly process.

In the data input and output stage the HTC VIVE device is considered to interact with the environment, connected to a computer using a HDMI port, which adds all the visual quality of the environment and the IR cameras connected by USB reads the movements of the hand controls in the environment. The communication is established due to the Steam VR software and its respective libraries that allow programming the interaction with the control actions, in addition to the compatibility with Unity 3D software.

The Scripts phase contains the communication with the I/O devices, as well as the development of the virtual interface that interacts in the different assembly areas which obey industrial safety regulations since it is where each of the pieces of the environment to obtain the respective response of the output device, emphasizing audio responses with surround sound because it plays a very important role in the user's immersion.

The simulation is a stage of great importance, the presented application has pieces developed parametrically in CAD format software, in this case SolidWorks is used due to the friendly interface and the versatility to create 3D models, as well as 2D planimetries that facilitate the dimensional comprehension of the assembly.

These pieces are exported to the 3DSMax software to convert them an extension file .FBX which is compatible with Unity 3D, the main program of the application that gathers the characteristics for communication and interaction with stations of assembly, sheathing and painting of the bodywork. In this way the body assembly is recorded in the following order where the structure of the bodywork is composed of several main stages.

4 Bodywork Structure

The application presents the assembly of the metallic structure of a bus, which depends exclusively on the design provided by the manufacturer. Even so, every bodywork contains quite similar structures with elements and sets of basic parts which are described below.

Chassis. This element is defined by a Torpedo-type chassis as shown in Fig. 3, with an engine ahead of the front axle and mechanical crossbow type suspension, this type of chassis covers 90% of national bus production.

Fig. 3. Torpedo-type chassis

Anchors. These elements allow anchoring the floor of the bodywork to the main chassis, obeying the rules of the chassis manufacturer which strictly prohibit welding directly to the main beams, as indicated in Fig. 4. These elements are adjusted with screws in perforations specified by the manufacturer in order to distribute the weight in an equitable manner.

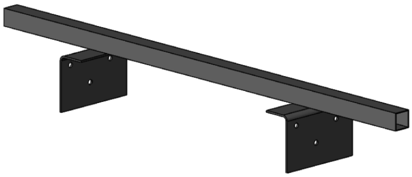


Fig. 4. Anchorage

Floor. Visible in Fig. 5, it is comprised of a structure of square steel tubes of 50 × 50 mm, uniform structure, mesh type, welded vertically, and coupled to the anchors with electric welding.

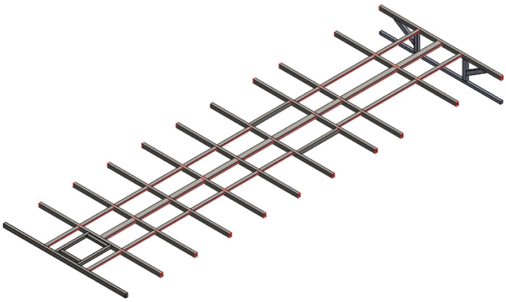


Fig. 5. Floor of the bodywork

Body. This structure is shown in Fig. 6, is comprised of galvanized iron tubes, arranged in specific sizes and shapes to support the roof and lined with the bus, this body is composed of serrated, frontal, rear and lateral supports, these elements are located individually and are welded together with vertical welding.

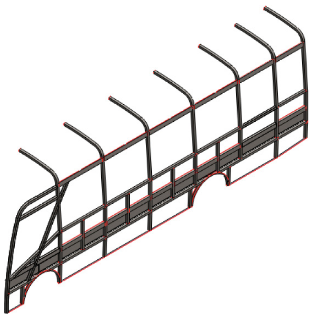


Fig. 6. Body of the bodywork

Ceiling. The roof structure is as light as possible so that the center of mass of the vehicle is as close as possible to the ground, as shown in Fig. 7, made up of square galvanized iron tubes and small tool plates to distribute the weight towards the searches.

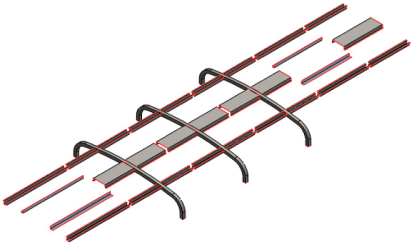


Fig. 7. Ceiling of the bodywork

Lined. The final stage of the assembly of bodyworks comprises a coating of tool plates, as indicated in Fig. 8, which provide firmness, stability and aerodynamics to the working conditions of the vehicle.

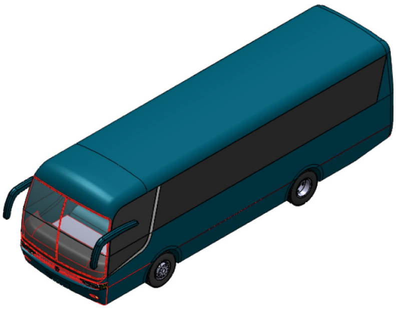


Fig. 8. Lined of the bodywork

The elements described above are part of the virtual application, and can be manipulated by the user through the controls of HTC VIVE device, in addition to the free movement of the user in the virtual plant including stairs that allow access to the assembly on the roof of the body, providing a realistic environment that facilitates the immersion of the human being in Virtual Reality.

5 Process Programming

For the immersion in the presented application the realism of the elements is indispensable, for that reason the design of the parametric model in a CAD software is made. In this case, the Solidworks software is used, a tool focused on mechanical design in 2D and 3D since it allows modeling individual pieces and in sets, besides

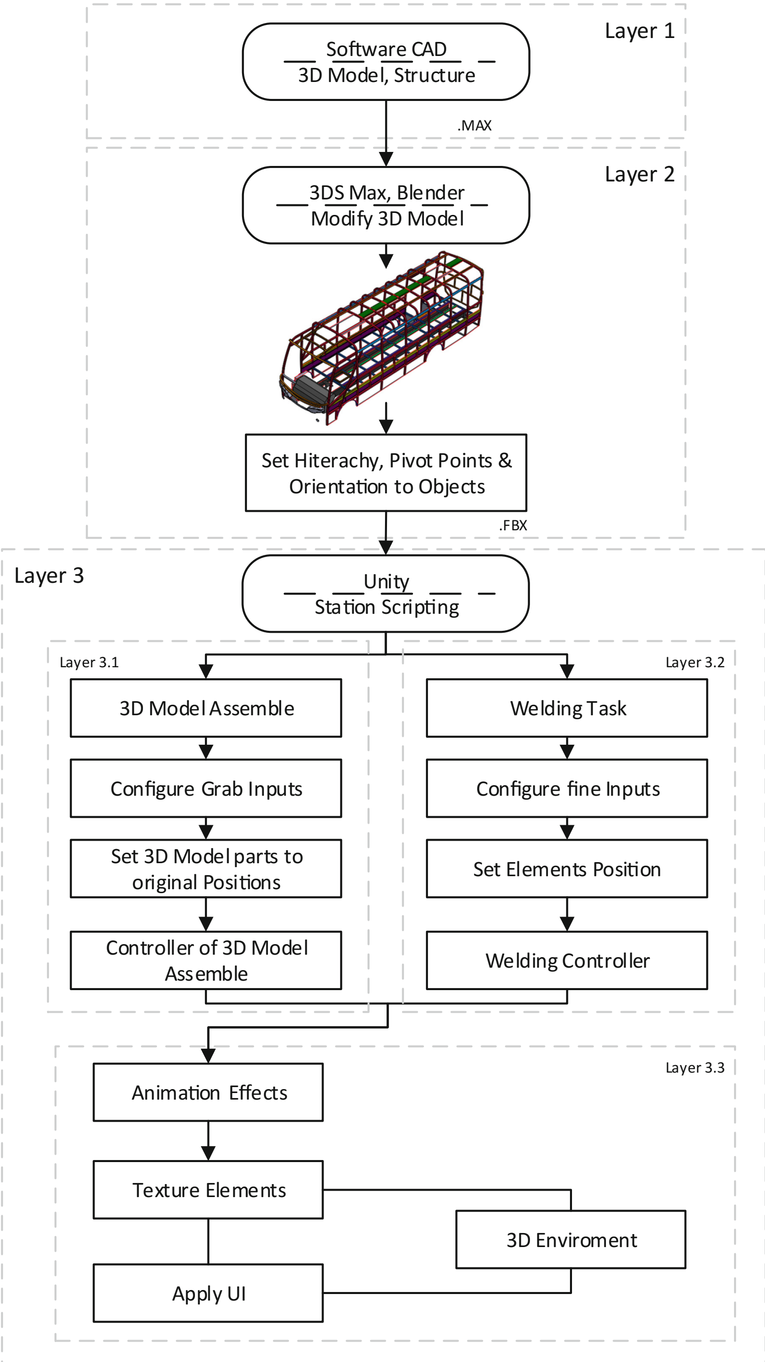


Fig. 9. Structure model

extracting from them planimetries or any other technical information of the element, its versatility is that once the piece has been made, all the extractions (planes and exchange files) are done in a automated way.

This document proposes a multi-layer scheme focused on immersion and the development of virtual applications for automotive assembly and electric welding tasks as shown in Fig. 9.

(i) Layer 1. In this section the design of each 3D CAD model corresponding to the parts that interact in the assembly of bodyworks such as anchors, bars, searches and linings, elements designed to work in Unity 3D is developed, for this the use of the 3ds Max software. So, in *(ii) Layer 2,* based on the assembly references, the hierarchy and orientation of each piece of the model is determined as well as standardizing them in the same coordinate system. Thus, it establishes the axes of rotation or pivots of each element for tasks of rotation. By completing this process you get a .FBX file compatible with the Unity 3D graphics engine where the next layer of the process is developed: *(iii) Layer 3,* characterized by a Unity software scene, which was initially responsible for defining the process station and the task to be performed, here the interaction between the input and output devices is performed with the environment where the application is executed. This section contains 3 subroutines established by *Layer 3.1. Assembly tasks,* the programming of the application made in C language, contains Scripts linked to each element that interacts in the process. In the assembly subroutine the entrances are configured for the movement interaction of the bodywork parts towards their respective position in relation to the original 3D model, task carried out with HTC VIVE & Gear VR devices, directed by the assembly controller with *Trigger functions* where it compares the current position of a piece in space with its respective position to the original model which retains the invisible feature. Thus, the drag of the piece is assigned to the TRIGGER button of the HTC control, visible in Fig. 10.

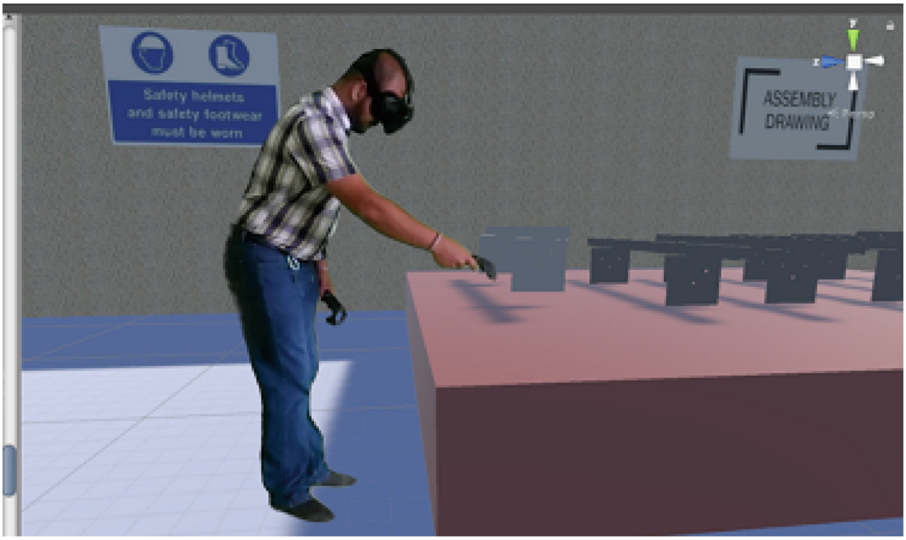
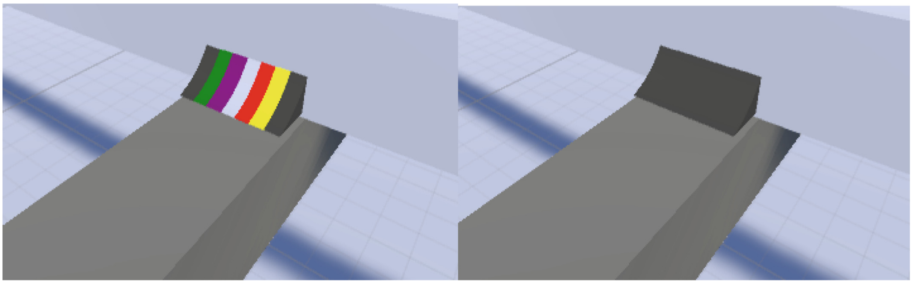


Fig. 10. Drag parts

The consequent subroutine is called as *Layer 3.2. welding tasks.* Where the inputs of the HTC VIVE device are configured in such a way that the application interacts with tiny movements of the electrode, associated with the HTC VIVE device to perform the corresponding animations around these movements. The welding effect is represented by several solid elements, visible in Fig. 11, which appear sequentially by keeping the electrode in correct position for a defined period of time. Finally, the *Layer 3.3, Animación.* consists of immersion effects defined by specific effects of each task such as *(i)* assembly animation where the assembly plans are visualized when the HTC VIVE control is located in a space delimited on the wall of the simulation, as shown in Fig. 12. *(ii)* For welding tasks, particle systems are used, which provide visual effects of sparks, smoke and welding flames, visible depending on the position of the virtual electrode with respect to the welded pieces.



(a) Weld Elements **(b)** Weld Effect

Fig. 11. Weld effect

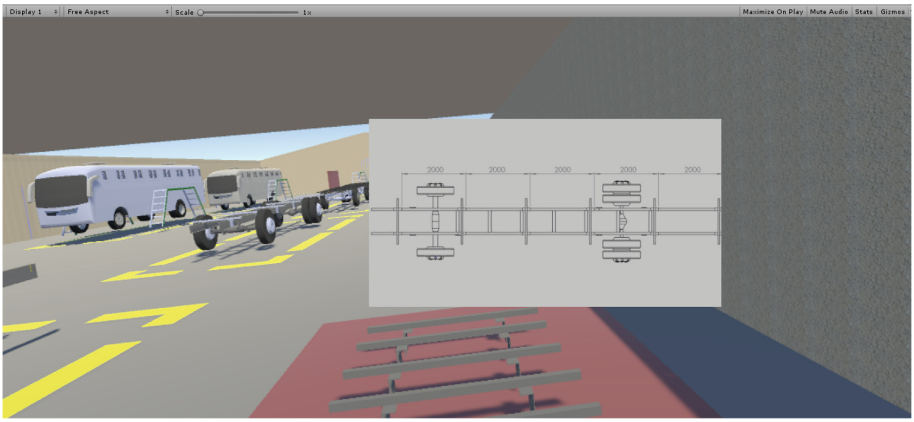


Fig. 12. Display of planes

6 Analysis of Results

The section presents a virtual environment of a bodyworks assembly plant, see Fig. 13, where user immersion is allowed when interacting with assembly and welding tasks in a realistic manner. The bus bodyworks factory has two main areas: *(i)* office area, where the administrative staff works, management and customer service. *(ii)* production area, where the manufacturing process is completely carried out to transform a chassis into a passenger bus with all available services.

Fig. 13. Bus bodywork factory

The assembly of bus bodyworks is composed of three main stages, grouped by the similarity of their tasks: *(i)* Assembly, *(ii)* Welding and *(iii)* Lining and painting. These tasks are developed with the HTC VIVE device, which provides the ideal feedback in order to develop a realistic environment. Next, each process is described individually.

Assembly. This process considers four sections of work with their respective pieces as shown in Figs. 14, 15, 16, 17 and 18, these pieces initially appear unarmed on a work table. The main objective is to use the HTC control to take and move each piece to the chassis in order to assemble the metal structure of the bus by placing each element in its corresponding position according to the layout of each planimetry. The first parts to be placed on the chassis are the anchors, the chassis manufacturer indicates the quantity and number of parts necessary considering the use of the vehicle, since they support the total weight of the structure. In the work carried out, a total of seven anchors are joined to the bodywork. See Fig. 14.

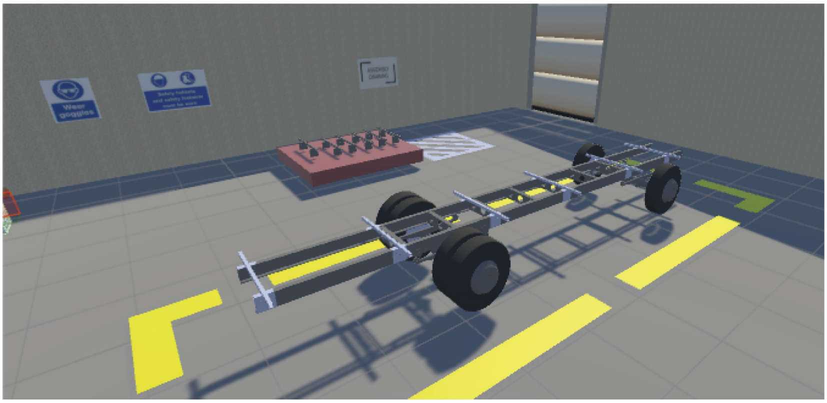


Fig. 14. Anchors area

For the assembly task it is required to interact with the planimetry of each section, see Fig. 15, and use the HTC VIVE control to move each piece to its corresponding position, in the case that the task is carried out successfully, the color of the piece changes and it is restricted to continue with the movement. See Fig. 16.

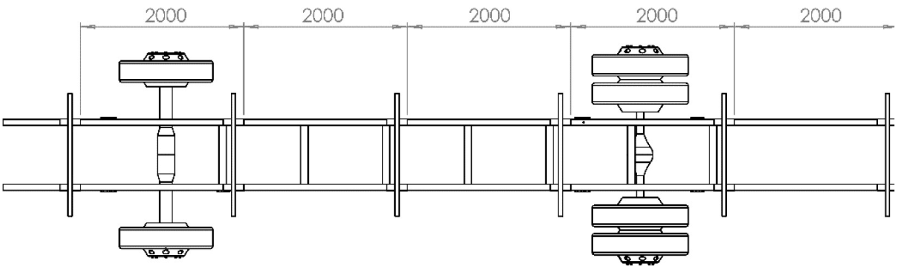
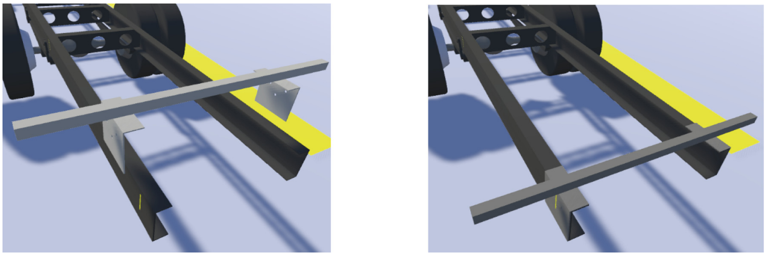


Fig. 15. Anchors station plans



(a) White Anchor while moving. (b) Black Anchor, correct position

Fig. 16. Assembly animations

For tasks of displacement in the environment, it is possible to walk within the area established by HTC VIVE, while, if you want to travel greater distances or move a piece, you must press the touch panel of the remote control and choose the desired location with the pointer that moves on the floor. See Fig. 17. It is possible to use a control for scrolling while an object is dragged by another control.

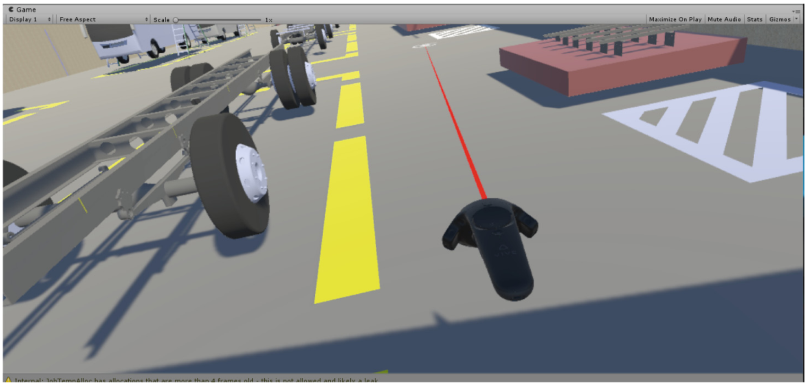


Fig. 17. Teleportation

The floor structure is welded on the anchors, this mesh is constituted by two main support bars on which rest twelve bars located transversely, as shown in Fig. 18, in this way the weight of the structure is held uniformly.

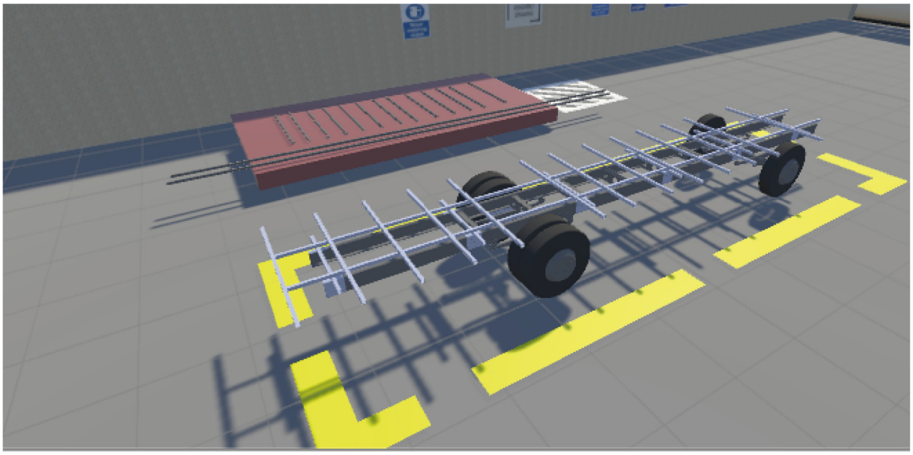


Fig. 18. Floor area

The next work station corresponds to the placement of eight searches, welded to the crossbars of the floor as shown in Fig. 19, form the main frame of the bus where it is possible to perceive its most basic dimensional characteristics.

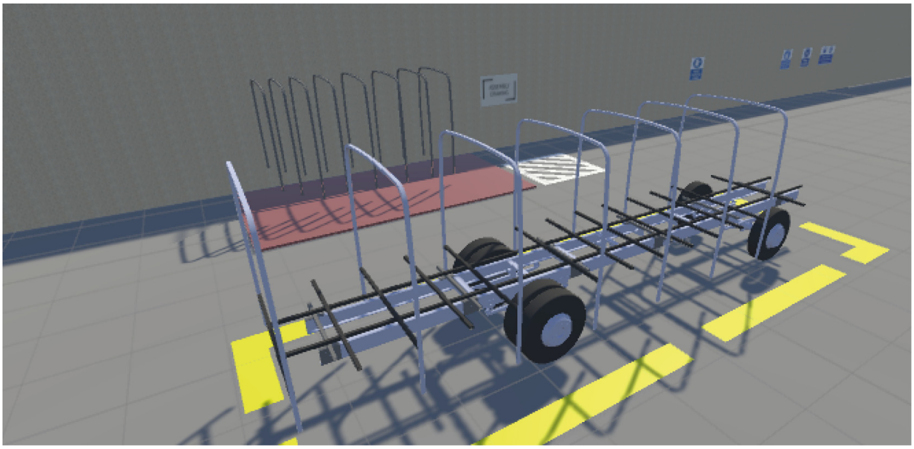


Fig. 19. Main structure area

Finally, approximately 120 pieces of square pipe are located and welded between the searches and the floor to form the main skeleton of the bus, see Fig. 20. In this way they form a solid and resistant structure ideal for the harshest conditions of passenger transport.

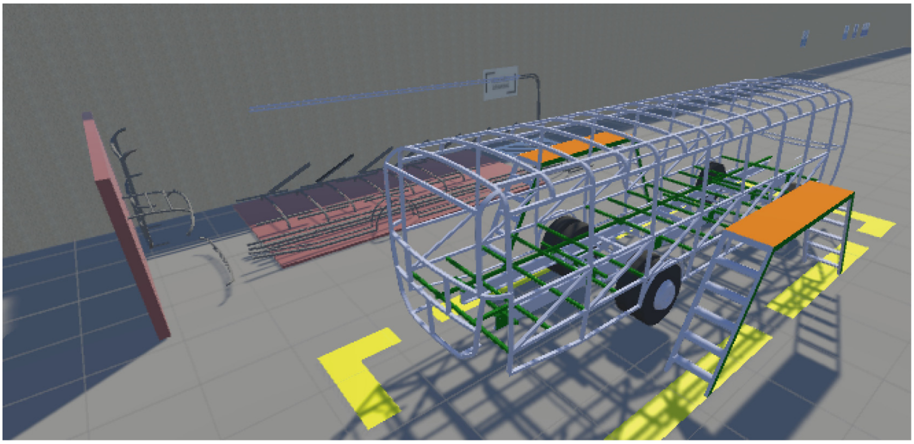


Fig. 20. General structure area

Welding. This process is involved in the whole assembly stage, since a strong and resistant joint between pieces is necessary to guarantee the quality of the structure. For the virtualization of this task several elements are considered such as welding machine, mask, electrodes of different characteristics and electrode holder. See Fig. 21.

Fig. 21. Welding area

The welding task provides a detailed sequence in which Unity 3D software initially considers the selection of the corresponding electrode for the material to be welded, the amperage selection and subsequent ignition of the soldering machine to finally manipulate the handle of the electrode holder, it is here where the displacement of the electrode is considered to produce visual effects, such as sparks, smoke and flames of colors and tactile sensory effects, which involves the vibration of the HTC VIVE control, in this way determining the state of the process and its correct development. See Fig. 22. The user can perform horizontal and vertical welding tasks as a sequential and realistic process.

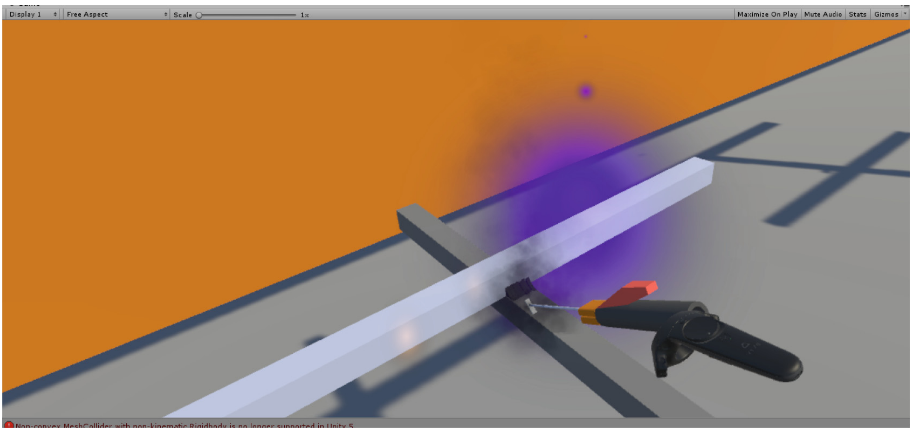


Fig. 22. Welding task

Lining and Painting. The metallic structure of the bus is subjected to a coating process, covered and sealed with metal sheets, as well as the front and rear pieces made with fiberglass. See Fig. 23. They use the recurring dynamics of taking pieces with HTC VIVE controls and place them in their corresponding positions.

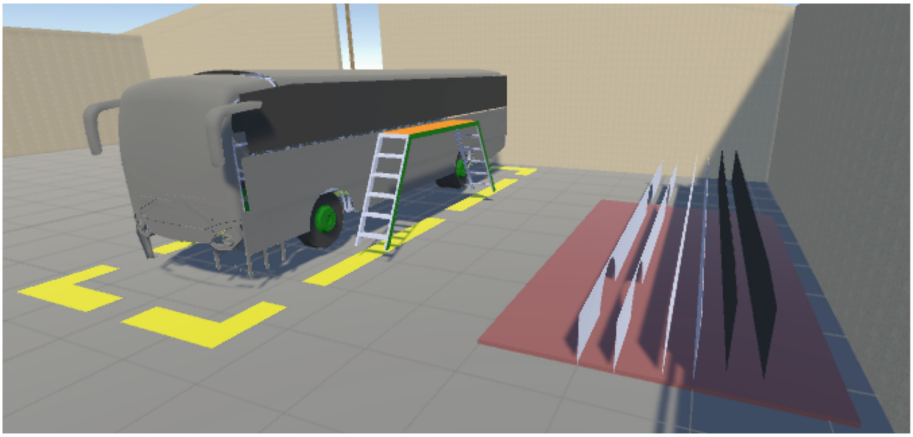


Fig. 23. Cover area

Figure 24 represents the area of facilities where the seats are placed and electrical and pneumatic connections are made. This stage of the bodywork is virtualized with the purpose of its theoretical knowledge.

Fig. 24. Seats and connections area

The painting area, visible in Fig. 25, consists of selecting and moving a predetermined color of several available, to paint the bus, according to the user's decision.

Fig. 25. Paint area

7 Conclusions

In this article, we propose a virtual training system for tasks of assembly and welding of bus bodyworks. A virtual reality environment developed with a graphics engine in Unity 3D is the fundamental basis of the system presented. In this way it allows the user to immerse during the teaching-learning process in order to reduce waste, optimize infrastructure, time and other variables. The experimental results obtained show the efficiency of the system which is generated due to the human-machine interaction oriented to develop psychosomatic abilities in the area of metallic bodywork industries.

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