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Research paper

Virtual simulation of a mechanical structure with 5DOF for induction hardening using Unity3D

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Abstract

In this paper we propose a mechanical structure with 5 degrees of freedom, designed to be used for induction hardening of metallic profiles which are used in building framed structures. All 5 joints of the proposed mechanical structure are prismatic, required to move a metallic profile through the inducer. The simulation was achieved using Unity3D software which provides the virtual environment needed for our purposes. To use the virtual simulation of the structure, we have had to build software components to help us gain access to the simulated components during the simulation. More components were added to implement the user interface and also the management backbone of the entire simulation. All of the software components which are used to interact with the mechanical system or its joints have been configured individually, supplying environment or physical variables for each component.

Keywords: *induction hardening; simulation; unity3D; virtual environment.*

1. Introduction

While metallic frame buildings are gaining popularity, the industrial process of building these structures is continuously being improved. For this, an approach is to use induction hardening for certain elements of the structure, to improve their strength and maximum load. But induction hardening is not an easy process to use, because of several parameters which need to be configured, one of these being the induction swipe speed. While other researches focus on different alloys to be hardened [1] or on the preheating process [2] before doing the induction hardening, other test the effect of high frequency induction on different applications [3-5]. Porpandiselvi (et. all) [6] achieved a new induction hardening process in which they use two different inverters to harden a required object with high and low frequencies. But Neumeyer (et. all) [7] managed to simulate the induction hardening, demonstrating how the profile temperature is time dependent and can be calculated using finite element analysis, and optimize power and frequency for the hardening process.
What we want to achieve in the end, by using the proposed mechanical structure, is a controlled system which can vary the velocity of the metallic profile while being subjected to the induction hardening process. In this paper we present the mechanical structure which will achieve the induction hardening, simulated using Unity3D. For this we have had to build our own virtual environment and import the 3D structure, while developing software modules to help with the simulation.
While Mahayudin (et. all) [8] is studying ways to visualize virtual environments by using Unity3D, Ruzinor (et. all) [9-11] have researched the way to simulate big virtual working environments, and Shin (et. all) [12] studies how to develop the 3D virtual environment and how to navigate through it for simulations on navigation in virtual scenarios.
Even if the researches using the virtual environment Unity3D are at the beginning, Chen (et. all) [13] have developed a virtual application for testing a 3D vehicle inside the Unity3D software. Also, research on virtual environment provided by Unity3D was not limited to terrestrial vehicles, but was also conducted on aerial UAVs [14].
Certain researchers have even used Unity3D to simulate through animation, testing of real robots by connecting them with the virtual environment through specific interfaces [15, 16], allowing the robot to experience different simulated scenarios.

2. Proposed mechanical structure

The proposed mechanical structure Ro CIF VIP [17] with 5 degrees of freedom is presented in figure 1. The structure is made to apply induction hardening treatment on metallic profiles of length no more than 60cm. The structure can be divided into 4 main sections according to their designation. The first section contains two prismatic joints. One joint is for grabbing the metallic profile (top green part in figure 1) when the user inserts it inside the machine, and the other is for sliding it down through the inducer (top yellow part in figure 1). The second section is made out of the inducer and cooling system (the inducer has magenta color in figure 1). At this point this section has no degree of freedom. The third section is similar to the first as it consists of two prismatic joints. The first one will grab the metallic profile (bottom green component in figure 1) as it comes out of the inducer, and the second will slide the profile down through and out of the inducer section (bottom yellow component in figure 1). The fourth and final section is the extraction system (blue part in figure 1). This is made out of one prismatic joint and it will take out of the mechanical system the metallic profile when the induction process was completed.

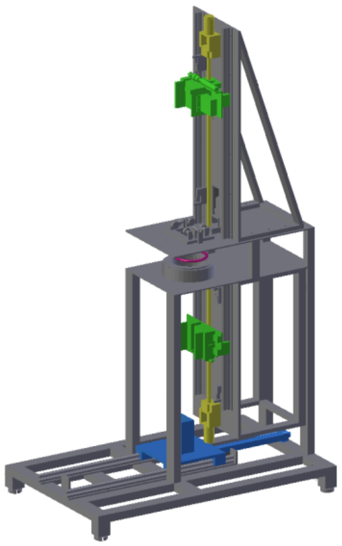

Fig.1. Proposed mechanical structure of Ro CIF VIP with 5 DOF

3. Unity3D integration

For each prismatic joint described and presented in figure 1, we have had to simulate it in the virtual environment. This was achieved by adding prismatic joints to all 5 degrees of freedom. Unity3D provides many tools for building a virtual simulation but it does not provide a specific prismatic joint component. This is why we have had to add one, ourselves.

The main advantage in working with Unity3D is that it provides the possibility to create new components, starting from existing ones or just starting from scratch. The other advantage is working with C# which is an advanced programming language. With this we have created several components of the simulation.

Fig.2. Translation Joint Class diagram

The component presented in figure 2, is the Translation Joint class which implements a prismatic joint. We can see in this figure that the class has several fields of data and methods to compute different parameters or methods that allow external objects to access data information.

One important component of the Translation Joint class is the OnPositionChanged Event. This event, which is present in figure 2, will be triggered every time the joint will move. This will allow any components to be executed when the joint is moving, to check if the position is close to a position constraint or to trigger a proximity sensor. With this component we can easily simulate proximity sensors, or just to detect when the joint is moving.

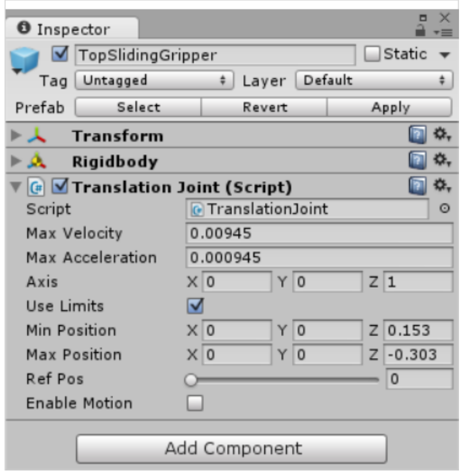

Fig.3. Top sliding prismatic joint

Fig.4. Bottom sliding prismatic joint

Fig.5. Top gripper prismatic joint

Figures 3 through 7 presents the prismatic joint components added to the simulated mechanical components. As one can see, every component is configured differently, depending on each joint's parameters. In each figure, the top field states the name of the game object to which the joint component is attached. In this way, we can't make mistakes while configuring the component, because we always know which part is being configured. Also, in these figures there are several other components which we have not detailed, that contain the relative position of the game object (Transform component) and the physical parameters like mass and density (Rigidbody component). All of these components form just one small part of the entire structure, but when put together they form the virtual simulation of the entire mechanical structure of Ro CIF VIP [18,19] with 5 DOF.

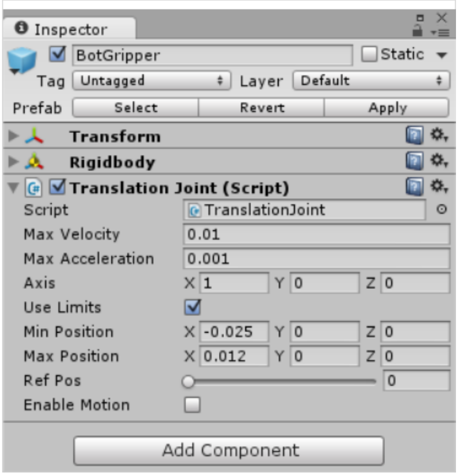

Fig.6. Bottom gripper prismatic joint

Figure 8, presents two components required to start the virtual simulation. The first component is the SimStarter component. This class was designed to get the actual machine into the scene when the simulation starts. If the machine is already in the scene, then it will not add a new one. The second component called Interface is the GUI component of this virtual simulation.
Figure 9 presents the Interface class diagram. This class has few variables, but has several methods called when the user presses a button to do an action. With the tools that Unity provides, we can build a good GUI in a short time that will fulfill our every need.

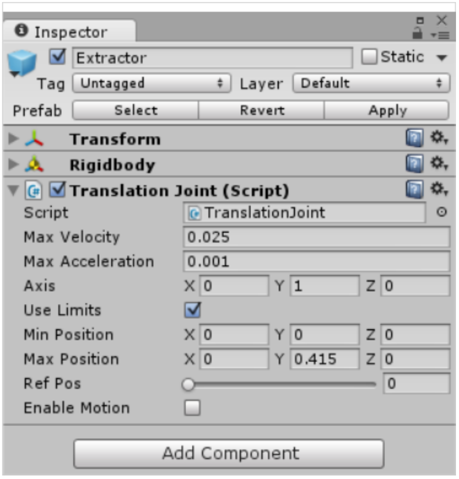

Fig.7. Extraction prismatic joint

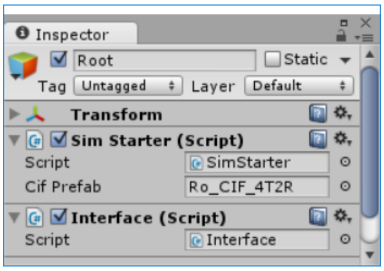

Fig.8. Root component which starts the entire simulation

Fig.9. GUI Class which provides commands to the user

Fig.10. GUI Class for navigating through the virtual environment

One important component during the simulation is the camera controller. This component will allow the user to navigate through the entire virtual environment, and observe the simulation from every angle he sees fit. The designed class for this feature is presented in figure 10. As one can see, it has only one method called Update, in which all the inputs are tracked, and five fields as variables. These variables are enough to move, rotate and zoom in/out the camera within the virtual environment, achieving the navigation component of the virtual simulation.
While the GUI and navigation components are needed for the human interaction with the virtual environment, we still need some components to link everything together. These components are the SimManager component and Ro_CIF_VIP component. They are presented in figures 11 and 12 as class diagrams.
The SimManager class is the backbone of the entire simulation. This is the place that links all the components, and with its help, any other component can get a reference to another, to use its data and properties. In this way, we can use the sensors attached on each component, to give automatic commands to the joints. By being the central component of the simulation, it has to be very well structured and clean. This is why there are no other components other that the initialization of each joint and the reference to each section of the mechanical system Ro CIF VIP.
While SimManager is the central point of the simulation, Ro CIF VIP class is the one to link every component found in SimManager to the actual object within the simulation. In Unity, we can say there are two types of components or classes. The first type is the class which inherits the MonoBehaviour class and can be present inside the simulation, having parameters, like the TranslationJoint class. The second type is the type that do not inherit the MonoBehaviour class. This class must have appropriate variables and must be instantiated by one class of the first type (a class that inherits

the MonoBehaviour class), of by a different type two class which at some point was instantiated by the first type.

Ro_CIF_VIP class is of the first type, and has a reference for each prismatic joint, plus the profile which is being moved. These references are assigned at design time, but can be changed during the simulation if we can find the reference to the objects required by the simulation.

Fig.11. Manager class diagram required for accessing the simulated components from within the app

Fig.12. Ro CIF VIP class component required to link the simulated objects with the manager variables

4. Conclusion

In this paper we have used the 3D model of a 5DOF mechanical structure (Ro CIF VIP) designed for induction hardening of metallic profiles, and simulated it using Unity3D. To achieve the simulation, we have had to build our own software components, at first to simulate a prismatic joint and after that to use it inside the virtual simulation. To use the virtual environment, we have built a user interface and a navigation component so that the simulation can be controlled by any user. But, to use all of these components, we needed a central point from where all of them could be called. This is why we have designed a manager, to link every part of the simulation, and provide software reference to each initialized component.

By using Unity3D software, we have created a virtual simulation of the proposed mechanical structure with which we can test and simulate the induction hardening process, to detect structural anomalies and test future intelligent control methods.

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