ELECTRICAL ENGINEERING:

PERSPECTIVE
AND TENDENCY

JOÃO DALLAMUTA
HENRIQUE AJUZ HOLZMANN
(ORGANIZADORES)

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CIÊNCIAS EXATAS E DA TERRA E ENGENHARIAS

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APRESENTAÇÃO

A engenharia elétrica tornou-se uma profissão há cerca de 130 anos, com o início da distribuição de eletricidade em caráter comercial e com a difusão acelerada do telégrafo em escala global no final do século XIX.

Na primeira metade do século XX a difusão da telefonia e da radiodifusão além do crescimento vigoroso dos sistemas elétricos de produção, transmissão e distribuição de eletricidade, deu os contornos definitivos para a carreira de engenheiro eletricista que na segunda metade do século, com a difusão dos semicondutores e da computação gerou variações de ênfase de formação como engenheiros eletrônicos, de telecomunicações, de controle e automação ou de computação.

Não há padrões de desempenho em engenharia elétrica e da computação que sejam duradouros. Desde que Gordon E. Moore fez a sua clássica profecia tecnológica, em meados dos anos 60, a qual o número de transistores em um chip dobraria a cada 18 meses - padrão este válido até hoje – muita coisa mudou. Permanece porem a certeza de que não há tecnologia na neste campo do conhecimento que não possa ser substituída a qualquer momento por uma nova, oriunda de pesquisa científica nesta área.

Produzir conhecimento em engenharia elétrica é, portanto, atuar em fronteiras de padrões e técnicas de engenharia. Também se trata de uma área de conhecimento com uma grande amplitude de sub áreas e especializações, algo desafiador para pesquisadores e engenheiros.

Neste livro temos uma diversidade de temas nas áreas níveis de profundidade e abordagens de pesquisa, envolvendo aspectos técnicos e científicos. Aos autores e editores, agradecemos pela confiança e espirito de parceria.

Boa leitura

João Dallamuta
Henrique Ajuz Holzmann

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CAPÍTULO 3

A VIRTUAL REALITY APPLICATION FOR TRAINING LOCOMOTIVE OPERATORS

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ABSTRACT: In the last decades, the usage of virtual reality (VR) systems for training has been driven by continuing technological evolution, search for sustainable processes, more engaging training and so on. Furthermore, training with VR enables users to absorb knowledge without being exposed to procedures that involves risks. The purpose of this paper is to introduce the creation of a virtual reality serious game to train drivers with a gamification strategy. In addition, we present the evaluation of the game through a form filled in by 60 volunteers.
KEYWORDS: Virtual reality, Training, Virtual prototyping, Computational modelling.

RESUMO: Nas últimas décadas, o uso de sistemas de realidade virtual (RV) para treinamento tem sido impulsionado por uma evolução tecnológica contínua, busca de processos sustentáveis, treinamentos mais envolventes e outros. Além disso, o treinamento usando a RV permite que os usuários absorvam o conhecimento sem serem expostos a procedimentos que envolvam riscos. O objetivo deste artigo é apresentar a criação de um jogo sério de RV para treinar condutores de locomotivas com estratégias de gameficação. Além disso, é apresentado a avaliação do jogo através de um formulário preenchido por 60 voluntários.
PALAVRAS-CHAVE: Realidade Virtual, Treinamento, Prototipagem Virtual, Modelagem Computacional.

1 | INTRODUCTION

The virtual reality (VR) is a tool that provides users a chance to experience computer-simulated reality (ZHANG and LIU, 2016). This can be used for training in industrial processes through serious games that have advantages over training in real environments. The serious games are those whose main proposal transcends entertainment, providing the user some kind of knowledge or training (MICHAEL and CHEN, 2005). Some advantages of these games are: cost reduction, flexibility execution time, running availability anywhere, guarantee of performing repetitions much more easily and availability to apply evaluation mechanisms (PINHEIRO et al., 2016). In addition, another outstanding advantage is the ability to conduct

training of processes that are inserted in the high-risk environments.

According to Sousa et al. (2010), the increase in the technical complexity of equipment and machines requires employees with higher-level qualifications. The increase in operating cost, increasing demands of production processes and the efforts that are required by technicians made companies seek new methods and tools to conduct training with lower investments.

The current trend in education shows that training through virtual reality enables the absorption of knowledge quickly and efficiently by students compared to traditional training using books, photos and videos. According to Ray and Deb (2016), the VR environments have great potential for improving the educational process, and they serve as teaching aids.

Over the years, it has been observed that students learn the best, when a variety of methods is used in the learning. The teaching methods based on virtual reality have the potential to revolutionise the educational process, when used in conjunction with contemporary teaching techniques. These educational methods are more attractive to students because they are flexible, attractive and easy to understand, for example, in the mining industry, where most processes are complex and difficult to explain (MITRA, HEBBLEWHITE and SAYDAM ,2015).

The research directions in virtual environments, gamification and serious games suggest that these tools can be very effective for education, and they provide unique advantages (RODRIGUEZ-GIL, GARCÍA-ZUBIA and ORDUÑA, 2016). The gamification can be described as the use of game development elements in activities that are not related to entertainment games, to make them more attractive (DETERDING et al., 2011).

Therefore, the gamification used in training systems in virtual reality may create greater interest among the users. So, users feel as though they are playing games which influence their behaviour, improve their motivation and enhance engagement (CHEN and DUH, 2018). The examples of elements used in the gamification are goals and rules, difficulty levels, game narrative, compensation system and feedback systems (FARDO, 2013).

According to Tichon (2007), driving trains is a complex task that involves a large number of difficulties and challenges. Tichon (2007) claimed that it is necessary to have the knowledge of train dynamics and emergency procedures, such as firefighting and evacuation training. As a result, the virtual reality applied to these systems can bring benefits when thinking about visualisation of procedures and training of the drivers. The training of these drivers using virtual reality can improve driving skills and improve actions taken in risky situations. This is an important factor for a large number of train accidents linked to human errors.

In this work, we present results of the development of a VR serious game that simulate the training of locomotive drivers using gamification techniques. The virtual environment created is based on the real environment of a mining company.

The main contributions of this work are as follows:

- an implementation of an efficient virtual reality serious game for training of the locomotive operator;

- the creation of 3D models, performed through a workflow, developed with a reduced number of polygons;

- the use VR to reduce the risks associated with driving trains;

- a subjective evaluation of training with two scenarios named "Scene A" and "Scene B", and the efficacy of these VR based training modes.

This paper is organised as follows: Section 2 describes the VR application design and development; Section 3 describes the evaluation of VR implementation; Sections 4 shows results and discussion; finally, the last section presents our conclusions and future works.

2 | APPLICATION DESIGN AND DEVELOPMENT

This serious game simulates the driving of a train, allowing the user to manipulate some controls present in a locomotive, such as the brakes, accelerator and horn. In the game, the train travels along a fictitious railway containing 3D models of railway signs and buildings, similar to the real objects present in this railway environment. The serious game was developed using gamification techniques, such as the insertion of scores and the number of lives of the user related to its performance in the game. In addition to ranking of users, who had the best performances and a training tutorial to guide users to perform the correct action, were presented in the game.

This serious game was built in the game engine Unity 2018.2 (unity3d.com), which allows the development of virtual environments and native integration with the head mounted display (HMD), and the controllers chosen to be used were Oculus Rift and Oculus Touch (www.oculus.com).

The 3Ds Max 2018 (https://www.autodesk.com/products/3ds-max) was selected as a program for modelling the virtual environment models. This software was used together with Substance Painter 2018 (https://www.substance3d.com), which is a 3D painting and texturing software. The 3D models of railway signs, buildings and train were modelled using a workflow for the creation of models with a reduced number of polygons, but characteristics similar to the real objects, ensuring the proper performance of the game engine (SILVA et al., 2018).

The 3D model of the locomotive was created based on the General Electric Dash 9-40BBW diesel-electric locomotive. The components of the locomotive panel (that have interaction, such as the brakes, accelerator and horn), were modelled with the help of the manufacturer's operating manual (GENERAL ELECTRIC COMPANY, 1997). This was important to maintain the main real operating characteristics of the locomotive in the virtual

environment. The 3D models of railway signs and buildings, as shown in Figure 1, was created based on a railway operation manual and computer aided design (CAD) files and photos of the real environments, provided by the research partner company.

The dynamics of the train in the virtual environment are dependent on the actuation of the three brake levers, the accelerator lever and the reversing lever. The C# programming language codes have been developed to calculate the values of speed and acceleration of the train, in relation to the positions that the game user actuates these five levers during execution. The locomotive panel has other controls that can be manipulated by the user, but that do not influence the dynamics of the locomotive, such as the horn, bell and warning system. In the case of the horn and bell, they sound when they are triggered by the user.
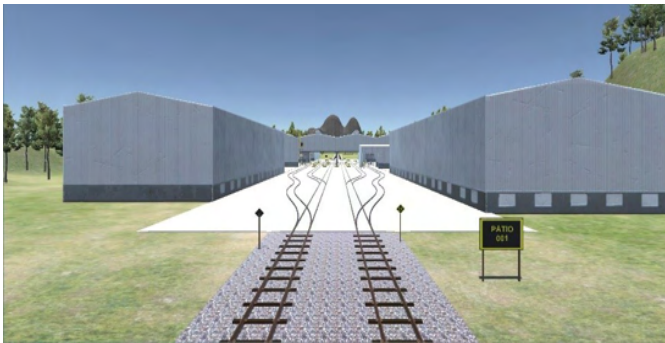
Figure 1. The 3D models of railway signs and buildings.

The levers and buttons on the locomotive panel are actuated by the user via the Oculus Touch index triggers and hand triggers. The vibration of the Oculus Touch controllers has been enabled to function as a haptic system, informing the user when a lever or button is manipulated. Figure 2 shows the activation of the horn lever by the user.

Figure 2. Use of the Oculus Touch to manipulate the horn lever in the locomotive panel.

To help the serious game user, a tutorial system was implemented to guide on the necessary actions for a driving, considered as optimal.

This tutorial presents the actuation info for the user on a screen positioned in front of the locomotive panel. This tutorial screen shows the actuation info—of which lever or button the user should actuate, to which position it should be actuated, at which moment it should be actuated and some complementary information, such as the direction of the actuation.

The actuation information are presented to the user as the train moves through the virtual environment. These actuation information were stipulated based on the optimal operation of the locomotive on the railroad of this virtual environment, i.e. if the user follows all the orientations of the tutorial screen, the locomotive driving will be equal to the optimal operation configured.

Comparing the user's actuation with the actuation info presented by the tutorial screen, a score is generated by the game and presented to the user during the entire execution. The serious game was developed with 37 actuations of levers and buttons, where each actuation can bonus the user with a maximum of 100 points. The number of points that the user gains in each actuation is maximum if it is performed in the exact position presented in the tutorial. The number of points is lower if it is performed before or after that exact position presented in the tutorial, decreasing linearly. If the user does not perform the actuation before the tutorial screen clears the actuation info, the game penalises the user with the loss of one life.

This serious game is divided into four scenes: (1) start scene, (2) main scene with few 3D models, (3) main scene with all 3D models and (4) end scene. The scenes in this software are a way to divide the development and execution of the game into pieces. Each scene is executed separately and contains its own environment, programming codes and menus. The start scene and end scene are presented on the computer screen, while the two main scenes are presented in the Oculus Rift. The two main scenes also present the visualisation on the computer screen, showing that the user has been using the Oculus Rift, so anyone near the user can follow the execution of the game.

In the main scene with all 3D models, the user can drive the locomotive in a virtual environment built with all 3D models developed in this work. The main scene with few 3D models, the user can drive the locomotive in a virtual environment very similar to the other main scene, except for the fact that some 3D models are not present. The examples of 3D models presented only in the main scene are locomotive maintenance and repair shop, locomotive fuelling service-station, wagon repair shop, train station (see Figure 3) and some railway signs with all 3D models.

These two main scenes were developed in the Unity software to compose the serious game to verify the following hypothesis: The number of 3D models in the virtual environment of the serious game has a relationship with the user's performance in driving the virtual train.

Figure 3. 3D models of a train station in the serious game.

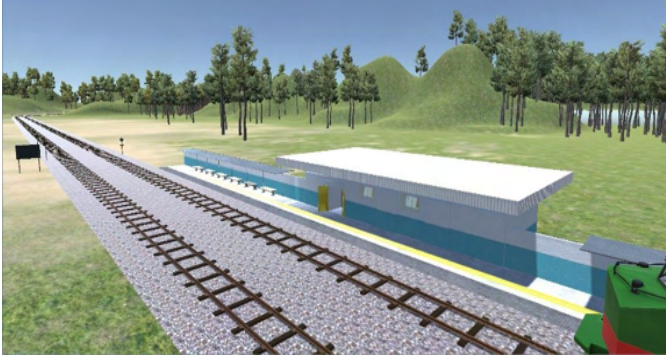Figure 4 shows the state diagram of the serious game. The first tree states represent menus that are part of the start scene, and the last two states represent menus that are part of the end scene.
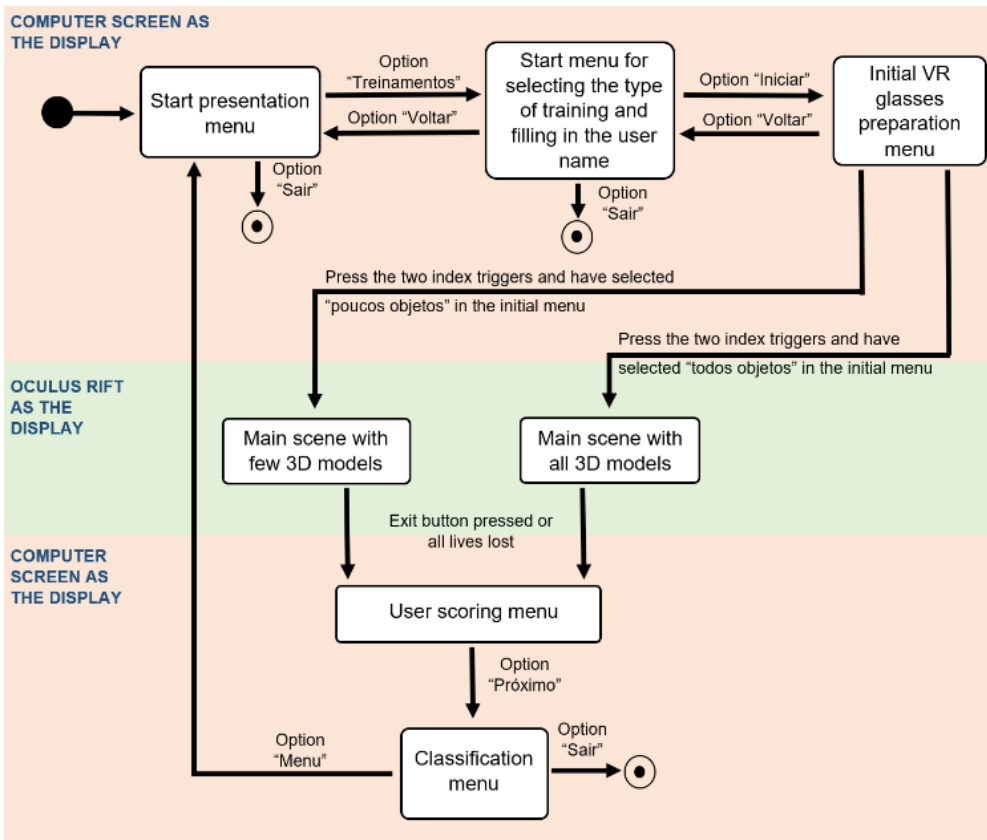

Figure 4. State diagram of the serious game.

3 | EVALUATION

To evaluate the developed serious games, tests with 60 volunteers were conducted after a formal authorisation by the ethics and research committee of the educational institution (identification code CAAE 97105218.1.0000.5072 – approval number 3.054.470) in the *Instituto Federal de Educação, Ciência e Tecnologia do Espírito Santo* (Ifes). The group participating in the tests was composed of students in the Ifes educational institution in the undergraduate course of electrical, mechanical and sanitary and environmental engineering and in the technical courses of electrotechnical and mechanical engineering.

The activities that the volunteers performed in the tests were: first, the execution of the serious game twice—once in each main scene, and secondly, the filling of a qualitative questionnaire. Figure 5 shows a volunteer carrying out the test in this serious game. This questionnaire contains 17 questions and statements with answers on the Likert scale (LIKERT, 1932) of 5 levels of intensity. This questionnaire contributes to evaluate the quality of immersion and presence of the virtual reality game through the opinion of the volunteers about the serious game, and the difference between playing in the two main scenes.

This evaluation method was chosen because of its great use in studies of virtual environment, identified through a literature review. Some of the questions and statements are: "How difficult was it to use the simulator?" (very difficult, difficult, neutral, easy or very easy); "I got used to the simulator environment quickly." (I totally disagree, I disagree, neither agree nor disagree, I agree or I totally agree); "The feeling of controlling the train in the virtual environment was realistic and natural." (I totally disagree, I disagree, neither agree nor disagree, I agree or I totally agree); "The objects in the simulator were instantly recognised." (I totally disagree, I disagree, neither agree nor disagree, I agree or I totally agree); "How often do you play video games?" (never, rarely, sometimes, often or always); "The objects in the simulator are similar to real world objects." (I totally disagree, I disagree, neither agree nor disagree, I agree or I totally agree); and "I think in the main scene with all 3D models I was able to drive better than in the other main scene, because there were more 3D models." (I totally disagree, I disagree, neither agree nor disagree, I agree or I totally agree).

In addition to the answers to the qualitative questionnaire, the score values of the volunteers, generated by the game in the execution of the two main scenes, were acquired. The order of execution of the two main scenes in the tests was randomly defined, so that 26 volunteers executed the serious game with the main scene with few 3D models first, and 34 volunteers executed the serious game with the main scene with all 3D models first.

Figure 5. A volunteer carrying out the test in the serious game.

4 I RESULTS AND DISCUSSION

To facilitate the presentation and analysis of the data from the users' score and the qualitative questionnaire, at first, the main scene with all 3D models was defined as "Scene A", and secondly, the main scene with few 3D models was defined as "Scene B". In addition, the sixty volunteers were divided into two groups: "Group 1", composed of 34 volunteers, executed the Scene A first and then the Scene B, and "Group 2", composed of 26 volunteers, executed the Scene B first and then the Scene A.

To statistically analyse the score values obtained by the volunteers in each scene of the test, it was necessary to divide all the scores in four groups of data:

- Data group 1A that contains the score values obtained by the volunteers of the Group 1 in Scene A;

- Data group 1B that contains the score values obtained by the volunteers of the Group 1 in Scene B;

- Data group 2A that contains the score values obtained by the volunteers of the Group 2 in Scene A;

- Data group 2B that contains the score values obtained by the volunteers of the Group 2 in the Scene B.

We applied the Lilliefors test and the One-sample Kolmogorov-Smirnov test in each

data group to evaluate the null hypothesis that the data comes from a standard normal distribution. It was possible to conclude that all the data does not have a normal distribution. Therefore, the Wilcoxon test for paired samples was applied in Data Group 1A and Data Group 1B, which returned the p-value of 0.00059389. As this p-value is much lower than 5%, the necessary condition for the results to be considered statistically equal, the Data Group 1A and the Data group 1B are statistically different. The same result was obtained by applying the Wilcoxon test in in Data Group 2A and Data Group 2B, with a p-value of 0.00073396.

The values of median for the four data sets are as follows:

- Median of Data Group 1A = 3091.5;

- Median of Data Group 1B = 3330.5;

- Median of Data Group 2A = 3398.5;

- Median of Data Group 2B = 3009.0.

With the results of the median and Wilcoxon tests, it is possible to conclude that all the volunteers had better performances in the second executions of the serious game compared to the first executions. So, in the tests with volunteers, the number of 3D models in the virtual environment of the serious game does not have a relationship with the user's performance in driving the virtual train.

The answers of two statements from the questionnaire, "*I think in the main scene with all 3D models I was able to drive better than in the other main scene because there were more 3D models.*" and "*I thought it took me less time to perform actions on the virtual locomotive in the main scene with all 3D models than in the main scene with few 3D models because it had more 3D objects.*", were "neither agree nor disagree". From these answers, it is possible to conclude that the number of 3D models in the virtual environment of the serious game does not have a relationship with the performance in driving the virtual train from the point of view of the volunteers.

By analysing the median, mean and mode (see Table 1) of results, given in the Likert 5-point scale of four statements from the qualitative questionnaire, we conclude that: the volunteers evaluated positively the serious game in relation to immersion and presence in the virtual reality environment.

Statement	Median	Mean	Mode
"I got used to the simulator environment quickly."	4.50	4.43	5.00
"The objects in the simulator were instantly recognised."	4.50	4.43	5.00
"The objects in the simulator are similar to real world objects."	4.00	4.23	4.00
"The feeling of controlling the train in the virtual environment was realistic and natural."	4.00	4.10	4.00

Table 1. Values of median, mean and mode of the answers of four statements from the qualitative questionnaire.

The opinion of the volunteers in relation to the quantity of 3D models in the serious game can be observed by analysing the answer to the statement: *"I prefer the main scene with all 3D models to the main scene with few 3D models"*. The median, mean and mode of all the volunteers' answers on the Likert 5-point are 4.00, 4.13 and 5.00, respectively. Thus, we conclude that the volunteers were more interested in using the game with more 3D models.

The opinion of the volunteers in relation to the interest in using the serious game can be observed by analysing the answer to the statement: *"I am interested in continuing to use the simulator"*. The median, mean and mode of all the volunteers' answers on the Likert 5-point are 5.00, 4.53 and 5.00, respectively. Thus, we conclude that most volunteers would be interested in continuing to use the virtual reality system.

Another hypothesis observed in this work is if the frequency of use of the video games is related to the performance of the user. This hypothesis is analysed by cross-referencing the data of the scores obtained by the volunteers and the answers of the questionnaire question: *"How often do you play video games?"*. Table 2 shows the mean score of the volunteers separated in relation to the response of the frequency of the use of video games. To verify this hypothesis, it was using the maximum score of the volunteer between the two scores obtained in the tests of the serious game. The mean values obtained show that volunteers who had a higher frequency of video game usage (often and always) had better performance in the serious game.

Question answer	Average maximum volunteer score for each answer
Never	3214.4
Rarely	3188.0
Sometimes	3224.7
Often	3361.2
Always	3410.0

Table 2. Mean score of the volunteers in relation to the questionnaire question: "How often do you play video games?".

5 | CONCLUSIONS

This paper aimed to describe the development of a virtual reality serious game for driving trains, to be used through the Oculus Rift and Oculus Touch. This game was developed through the Unity game development software, 3Ds Max modelling software and the texturing software named Substance Painter.

The creation of 3D models was performed through a workflow developed by this author and the other researchers, which was summarised in this work. With this workflow, it was possible to create 3D models with a reduced number of polygons, keeping similarity with the reality.

The developed game simulates the driving of a train in a virtual environment, enabling the activation of levers and buttons present in the control panel, found in the diesel-electric locomotives GE Dash 9 - 40 BBW.

All the codes that compose the game were developed by the author using the C# programming language.

The gamification techniques of classification, counting score, use of the training tutorial, insertion of the lives of the user and the development of selective menus were implemented to make the game more attractive and engaging from the point of view of the user.

The tests were conducted with 60 volunteers, where they ran the game in two specific scenes—one with few 3D models and another with all 3D models developed by the authors. The executions of the game generated score values related to the volunteer's performance, which was combined with the answers of a Likert scale qualitative questionnaire, completed at the end of the test. It was possible to statistically evaluate the hypotheses of this work.

It was concluded through the statistical tests that the users had better performances in the second scenes carried out in the serious game, compared with the first scenes carried out, regardless of the number of 3D models present in these scenes.

Another point observed was that the volunteers who had a frequency of video games' usage to be "frequently" or "always" obtained scores, on average, higher than the volunteers with the frequencies of usage to be "sometimes", "rarely" or "never".

Finally, the opinion of the volunteers regarding immersion and presence in the developed virtual environment was positive, and this opinion was obtained through the analysis of some of the answers of the questionnaire.

For future works, the creation of a version of the game is proposed to be executed through more financially accessible hardware, such as those that use smartphone gadgets and Bluetooth controls. It enables making the game logistically more viable, because it does not need a computer desktop to run.

Another proposal is to verify the option of driving in different weather conditions and times of the day, such as rain, fog, driving during the day and night. Different relief options can also be created and added, enabling the development of training for starting, driving and stopping in situations of slopes. In addition, new 3D models present in railway environments can be inserted to make the game more realistic.

Because the calculation of the user's score by the serious game is based on the position of the train in the virtual environment, i.e. the position of the train is compared to the position of the determined actions as ideal, an adaptive method of calculating the user's score can be proposed. In this proposed adaptive method, the calculation must be dynamic in relation to the actions taken by the user in the game, to always seek the best train driving, meeting certain configured requirements.

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