Low-cost 3d modelling of a go-karting circuit using drone based photogrammetry

Modelado 3D low-cost para integraren un simulador un circuito existentede karting mediante fotogrametría aérea con drones

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RESUMEN

- Los simuladores de vehículos se emplean ampliamente en disciplinas como la Fórmula 1, fabricantes de vehículos comerciales, vuelos militares o civiles, etc. Permiten evaluar el diseño del vehículo de forma más rápida y barata que por los métodos tradicionales, e incluso permiten hacerlo antes de que el prototipo esté fabricado. Estos simuladores de conducción se componen por un hardware, con el que interactúa un conductor y, un software que controla el modelo matemático del automóvil y la pista, encargándose de resolver la física entre ambas partes y procesando la imagen que se muestra en pantalla. El circuito en el que discurre el coche juega un papel fundamental en todo esto, por lo que en este trabajo se propone un método de bajo coste que permita modelar pistas de carreras, y que, posteriormente, se integre en el simulador de alta fidelidad ubicado en el centro Automotive Intelligence Centre – AIC en Amorebieta, País Vasco, España. El modelo 3D presentado corresponde con el Circuito de Vilariño Motorsport (Olaberria), obtenido por fotogrametría aérea con un dron consiguiendO una resolución de 3,4mm/px y un error máximo de 50mm, siendo además un método rápido y de bajo coste respecto a otros sistemas de captura de datos como es el LIDAR.
- Palabras clave Simulador de conducción, Formula Student, Fotogrametría Aérea, Entornos virtuales.

ABSTRACT

Vehicle simulators are widely used devices in disciplines such as Formula 1, design of commercial vehicles, military or civil flights, etc. They enable the evaluation of several aspects of a vehicle during the design phase. Driving simulators are composed of a hardware, with which a driver interacts, and a software that contains the mathematical model of the car and the track, which is also responsible for solving the physics between both parts. An important part of this set is the interaction with the circuit where the car should run, especially if it is a real track-based model. In this work a low-cost method is proposed for modeling a circuit and its integration into a professional simulator located in the Automotive Intelligence Centre – AIC, Amorebieta, Basque Country, Spain. The 3D model presented corresponds to the Vilariño Motorsport Circuit (Olaberria), obtained by aerial photogrammetry with a drone achieving a resolution of 3.4 mm / px) and a maximum error of 50 mm being also a fast and low-cost method with respect to capture systems with LIDAR.

Key-words: Driving Simulator, Formula Student, Arial Photogrammetry, Virtual Environment.

1. INTRODUCCIÓN

Formula Student is an international race car design contest which pursues the Engineering excellence. The competition gives students the opportunity to go further in their education by designing, building and competing with a single seat racing car. This first began in Europe in 1998, in England, carrying over the original Formula SAE competition with the addition of some supplementary regulations. Since then, more than 400 universities from all over the world have participated in the event. Having seen the success of the competition, in the last 10 years the event has also been held in other countries such as Austria, Germany, Hungary, Italy, Spain, etc.

The vehicle design follows the typical V-Shape process (Figure 1), widely employed in the automotive industry. The main notion of this design philosophy is the need to contrast vehicle theoretical specifications or concepts with the built reality at each manufacturing, assembly and testing stage.

For example, if one of the vehicle main attributes is "easy to drive", once the vehicle is built, the driver should identify this characteristic when testing the car. Additionally, one of the main challenges when defining the concept and main attributes is the breakdown of completely objective metrics, which will be further converted into system specifications. For example, the attributes "easy to drive" may be linked with the vehicle's understeering gradient, yaw rate gain. roll damping, or other parameters [1]. This breakdown has been traditionally difficult to carry out, as, in order to check the influence of a certain parameter, the complete vehicle should be built, modified, and tested.

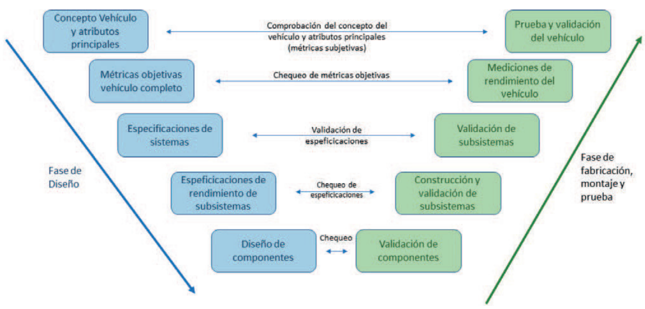

Fig. 1. Typical automotive V-shape design process

The hardware is composed of a moving platform and a cabin. A typical moving platform has six linear actuators and it's commercially named as "hexapod" or "Stewart Platform". Thanks to the actuators, the simulator has 6 degrees of freedom. Besides the linear actuators, the whole system can also be mounted on a sliding XY platform which can better reproduce linear acceleration (a "hexapod" can only reproduce short and transient accelerations and are usually coupled with roll and pitch movements). One of the biggest driving simulators in the world is in the Higashi-Fuji Technical Centre of Toyota. The cabin imitates the sitting position of the driver. Cabins may go from having just a simple steering wheel and pedals, to the complete car resting on the actuators.

There are other simulators that can be seen in sectors such as flight training, medical training, etc. Coming back to the automotive industry, Formula 1 teams use these simulators, in which there are three interesting key elements: the car, the racetrack and the driver who must interact in this environment. Virtually all automotive companies use driving simulators. Some of the companies that develop simulation software are: IPG Automotive, AVL VSM or CarSim. Besides, companies such as CRUDEN, VI-GRADE, McLaren, OKTAL or Ansible Motion manufacture this type of simulators. There are also simulators intended for the pure training of train or bus operators, such as those designed and manufactured by the company Lander Simulation & Training Solutions.

The simulator employed (Figure 3) by the Tecnun eRacing Formula Student team is located at the Virtual Development Centre of AIC – Automotive Intelligence Centre, in Amorebieta –SPAIN. The VDC is equipped with a Hexapod type of driving simulator from the CRUDEN brand. The simulator is equipped with a moving platform operated by six electric linear actuators, which enables six degrees of freedom. The cabin comprises the cockpit of an Audi A6 vehicle. The whole set is controlled by software with modular architecture that provides flexibility for its development.

The vehicle is modelled using IPG-CarMaker, a software responsible for solving the physics that arises from the driver / vehicle / track interaction and continuously communicates with the PANTHERA software used by the CRUDEN simulator. PANTHERA generates the graphics and sends the information to the actuators that allow the simulation of the movement of the vehicle. Normally, this simulator has an integrated generic track.

Before driving on the track, it is necessary to accumulate more hours of driving in a simulator than on the track, so data quality is checked. The two key elements in the simulator are: the car model and the digital model of the track. The car model is developed by

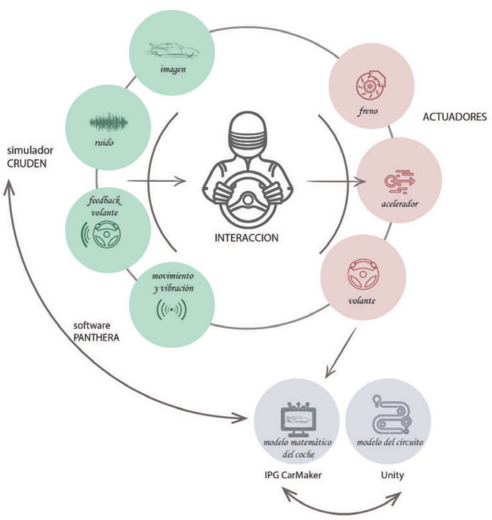

Fig. 2. Driving simulator elements

Fig. 3. CRUDEN driving simulator at AIC – Automotive Intelligence Centre

each Formula Student team, but the track they must race on is common to all. The modeling of circuits for professional simulators is carried out by some companies like iRacing. Modelling is performed by laser scanning and post-processing by a team of 3D modeling experts [3-4]. The equipment used can cost € 100,000 (AT960 Leica). This equipment offers by default dynamic measurements at high speed, it has 6 degrees of freedom to carry out inspections automatically. Thousands of points are obtained and, when these are properly processed with other programs, the mesh is obtained.

Lastly, the validation tests of the car are carried out at the Vilariño Motorsport circuit (Olaberria-Spain). Having information pertainting to the real track, which has been previously modeled and entered in the simulator, offers a large number of inputs that allow the contrasting of the data obtained with the simulator and the actual driving on the circuit.

This article contains a method that allows the topography of the track to be obtained, whatever it may be, quickly, at a low cost and with acceptable precision to validate the vehicle. A drone (Phantom 4 RTK) equipped with a photographic camera was used to obtain images.

1.2. PHOTOGRAMMETRY USING DRONES

Photogrammetry is a set of techniques and methods that allow obtaining three-dimensional geometry and its measurements and the reconstruction terrain from images. The American Society for Photogrammetry and Remote Sensing (ASPRS) defines it as: " the art, science and technology to obtain reliable measurements of physical objects and their environment, through recording, measurement and interpretation of images and patterns of radiant electromagnetic energy and other phenomena". Obtaining this information is done by various methods depending on the scope.

Pictures taken by a special camera located on an airplane can be used. The distortions in the photographs are corrected using an apparatus called photogrammetric restorer [5]. This device creates a three-dimensional image by combining overlapped photographs of the terrain taken from different angles. Boundaries, roads, and other elements are drawn from this image. The use of drones has made it possible to generalize the use of aerial photogrammetry and make it available to the user. One of the requirements was to perform the work at low cost, so it was decided to use drones for photogrammetric surveying. High quality images are obtained with yhe use of drones equipped with photographic cameras and video cameras [6-7]. Images that overlap longitudinally and transversely give accurate information about distances and elevations. These images are taken from different angles, which can be used to generate planes and carry out measurements of lengths, areas and volumes to be processed by a photogrammetric software that searches the common points of the photographs and creates 3D models with precision [8- 9]. The drone used for the topographic survey was a" Phantom 4" (approximately € 1,700).

There are several programs that process the information obtained from the drone, some of the most prominent are: Pix4D, Agisoft Photoscan, Drone2map, Opendronemap, VisualSFM, PhotoModeler, 123D Catch and Ortodrone. Guzman [10] carried out a comparative study among these programs, and based on this study, DroneDeploy was chosen, which, although not as well known, is suitable in these circumstances.

Other programs, because they require the processing of images in the CPU of a computer, do not allow their use while working and require many hours to process the information. DroneDeploy works online and at a high speed.

In addition, this application is specialized for DJI drones, such as the Phantom 4 used in this work, and its interface is simple and intuitive. Various data can be obtained from the generated map, such as distances or volumes. In addition, a flight offers several types of maps, such as elevation maps. Maps can be downloaded in different types of files, however, the format used is * .OBJ, a file format used for three-dimensional objects that contains 3D coordinates (polygonal lines and points), and texture maps, among other information.

2. METHOD: VIRTUAL ENVIRONMENT. MODEL 3D

2.1. STARTING DATA

The track Circuito de Olaberría was previously modelled using IPG-CarMaker software but could not be exported directly to the CRUDEN simulator. GPS coordinates of the circuit were acquired manually by a student, using a GPS antenna connected to a laptop. These coordinates were used as a starting point of the project. The longitude and latitude values were translated to Google Earth Pro for a quality check. The comparison showed that it was necessary to improve the coordinate's acquisition.

Data Acquisition / Environments	Precision	Use / Acceptance
GPS Global Sat G-STAR (BU-353S4) A first environment is created with IPG-CarMaker	GPS coordinates horizontal position <2.5m	From the data taken by the central area of the track, it is given a width that forms the road. Dismissed for lack of precision.
GPS: VectorNav VN-300	GPS coordinates horizontal 2.5 m vertical 5m	It is used for the tour in 3DSMax.
US Navy	Spain is not listed	It is dismissed
Iberpix IGN Gipuzkoa map images are obtained	Accuracy unknown as maps span km2	
SigPac Used for agricultural land	The file is an image. No precision established	It is dismissed
Google Earth *The image corresponding to the track is downloaded*	A scale relationship is established	3DSMax is used for the location of the track (2)
3DSMax *A second environment is created*		Both images (1) and (2) are used to create a unified environment that could be integrated into UNITY

Table: Various environments

Due to the lack of precision obtained, data was taken with a more accurate GPS. The VectorNav VN-300 inertial measurement system (IMU) was used. Data collection was performed by moving around the central area of the circuit. Data processed in MATLAB, -the information obtained corresponds to longitude (X axis), latitude (Y axis) and altitude (Z axis). Data to be interpreted by the IPG-CarMaker software. The height precision obtained was 5 m and horizontally 2.5 m; this data collection system was rejected, although it served as a reference to observe possible deviations.

Various sources of topographic maps were subsequently investigated to have an environment closer to reality. The US Navy's base of world topographic maps was checked, which was made using LIDAR technology. Some give meter precision. Unfortunately, Spain is not listed. MICRODEM, a US Navy computer program for map processing, was used to convert the orthographic map into a bitmap that could be used as a texture in 3DMax software. Later, the National Geographic Institute of Spain (IGN) was consulted to download orthographic maps of the environment. The download was made through the Iberpix online platform. The height data was found to cover square kilometers, a precision that did not provide convenient information. Finally, the SigPac viewer, a topographic map system of Spain, used for the distribution of agricultural parcels, allowed - using Photoshop - to create a black and white bitmap used in the first 3D model of the circuit. Table 1 shows the followed process.

2.2. 3DSMax MODELLING

The second terrain model was obtained from the images obtained from SIGPAC converted to gray scale for the generation of the environment and Google Earth. The track and the texture map are integrated on them. Both images are imported into 3DSMax software. The scale must be known, -as seen in Figure 4-, the starting image of Google Earth, has a yellow line that serves as a reference of 400 meters. The road should be built on this environment within the framework of the same program. Therefore, from the data obtained with the IMU, a spline could be drawn that corresponded to the final route.

Once the terrain has been generated and the path of the circuit has been obtained, the road is integrated into the environment. Mesh deformation tools provided by the same 3DS Max program were used to adjust the terrain to the road. This tool provides a flexible mesh grid that warps the image by repositioning grid lines, nodes, and patches; adjacent pixels are transformed under the line, node, or patch. The extent of the deformation depends on the complexity of the grid. With this work, the time required to obtain a model was observed. The method is approximate, the starting data has an accuracy of 0.5 m.

Once this work was done, it was decided to work with aerial photogrammetry, directly obtaining the images of the terrain to be processed later. This information can be carried out by various methods, either terrestrial photogrammetry or aerial photogrammetry. For terrestrial photogrammetry, a mobile system is necessary to transport the scanner along the circuit, while the aerial allows flying over terrain and obtaining the images that once superimposed and worked with the appropriate software, the 3D model of the circuit was obtained. The easiest way to obtain these images was to use a drone.

Regarding photogrammetry with drones, the following requirements were taken into account:

1. The land: 40,000 m2 of surface
2. The flight distance: currently limited by the Spanish law. It ≤

3. The maximum height: limited in Spain to 120 meters
4. The battery gives the flight a limited time. (30 'max flight time)
5. Good flight planning: take into account the weather, avoiding windy and rainy days, detecting the presence of objects or other data that may interfere with the flight

In order to improve the quality of the images obtained, in the flight planning, the most convenient flight height was determined. This is also related to the desired resolution, the available flight time, the possibility of conveniently managing the quantity of data obtained; taking into account that the lower the altitude, the longer the flight time will be required, so it was necessary to take into account the number of batteries necessary to carry out the flight.

2.3. FINAL TERRAIN ELEVATION

To design the flight mission, the area to be covered is defined first, which gives information on the estimated flight time, number of images to be taken and the batteries needed to cover the entire terrain in a single flight.

Three flights were made at different heights. The first one was at 61 m from the circuit, (Fig. 5a) this flight allowed the capture of the environment of the circuit obtaining the first 3D model in a single flight. The model was improved from the application, capturing images every 2 seconds and flying through critical areas for more detail. Later it was observed that the quality was improved by flying at a lower height. The second flight was made at 18.3 m, it was flown in two parts (Table 2) with the idea of showing the quality of the model that could be obtained as shown in Figure 5b.

The third flight was made at 12.2 m (Fig 6), a very low height, which allowed the capture of more details. This flight was divided into two missions to avoid collision with trees and buildings, since the application only allows pointing out the area of interest where there are no obstacles. It was obtained with a quality of 2in / px, which equals to an accuracy of 50mm and a resolution of 3.4mm / px. This could be improved by taking details manually and attaching them to the model. The available topographic alternatives give an approximate error of 1 m and 1mm specialized equipment is used. It should be mentioned that this method allows modelling the track in less than a day, while other methods need at least a week.

The resolution or GSD (Ground Sample Distance) indicates the distance between two consecutive pixels, measured on the ground. Let's take an example: 2-centimeter GSD means that one pixel in the image equals one 2-centimeter square on the ground. The lower the GSD value, the greater the spatial resolution of the model. For the GSD calculation, according to DJI, it corresponds to H / 36.5 cm / pixel, where H is the altitude of the aircraft relative to the scene in meters.

Fig. 4. 3Ds Max model

Each of the three models (Table 2) were taken on different days. The atmospheric conditions affect the data collection: the wind, the luminosity of that day, the temperature of that day. It was found that, on different days and at different heights, the precision of the track worsened (if they were joined in a single model), a necessary point to carry out the subsequent simulation.

Detailed photos of posters, garage facades etc, were taken in order to make the environment more realistic. In addition, different Prefabs-type details were added that are provided by the Unity Asset Store resource library: separator bars, cones, tires, trees, barrels, metal fences, panoramic horizon, etc. Once the images are processed, the DTM model is obtained (Digital Terrain Model).

3. RESULTS: INTEGRATION WITH THE SIMULATOR

The integration into the simulator requires a 3D model with the cartographic information of the circuit. On one hand, PREFAB elements that provide visual realism are introduced, and on the other hand, information on the roughness of the terrain that influences the grip of tires on driving [12] is provided. The coefficient of friction depends on two factors: tires and asphalt. The coefficient of friction of tires is calculated from the specific data available in a database of the "Tire Test Consortium" [13] and the coefficient of adhesion is taken as a standard value of $\mu = 1$ for dry asphalt and for $\mu = 0.9$ the patches [14]. The total coefficient of adherence between both surfaces, which is the determining factor, is calculated by multiplying the two values. This has a direct impact on the time it takes for the pilot to complete a lap of the circuit. In the simulation, these parameters will affect the noise and vertical excitation of the tire. Figure 7 reflects the integration process carried out. The terrain information obtained with the drone (* .obj file) is imported into the Unity software, which completes the elevation of the terrain with the different previously mentioned details.

Unity is a real-time 3D development platform created by Unity Technologies in 2005, available on various operating system platforms. From 2018, it was extended to support more than 25 platforms. It can be used to create 3D, 2D, VR, and augmented reality games, as well as simulations and other experiences. In the 2010s, Unity Technologies used its engine to transition to other industries using the real-time 3D platform, including motion picture and automotive. Automakers use Unity technology to create full-scale models of new vehicles in virtual reality, build virtual assembly lines, and train workers. Other uses Unity Technologies pursues include architecture, engineering, and construction.

Unity works with ASSETs. This resource can come from files created outside Unity: 3D models, audio, images etc. to which other resources created within Unity can be added such as audio mixers and textures or animations. The point mesh file formats that can be imported are *.FBX, *.DAE, *.3DS, *.DXF and *.OBJ.

At the beginning the starting position of the car must be indicated. Once the virtual environment has been prepared with the Unity program, it must be exported to the simulator in a compatible format that is readable by the PANTHERA software, the software used by CRUDEN for the simulator (Fig. 7). The developers of CRUDEN provided a manual to import the track from Unity, which indicates how the Unity file should be exported to have a format compatible with the simulator. The ability to render 3D content in the most realistic way possible is crucial to the success of a driving simulator. After many years in which PANTHERA has been developing its own rendering engine for driving simulators, CRUDEN has switched to the Unity engine. This has contributed to the integration with the PANTHERA software that works with the CRUDEN simulator and oversee

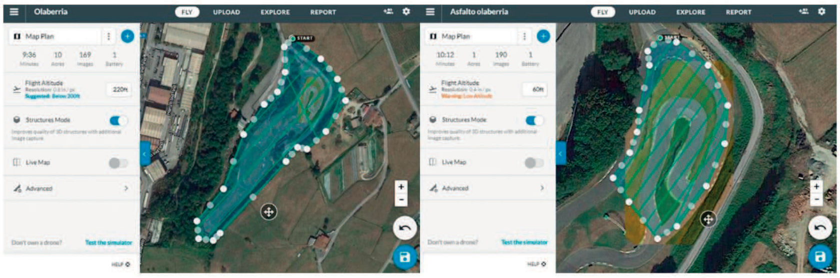

Fig. 5.a - (Left) First-model 61m, Fig. 5.b (Right) Second-model 18.3m

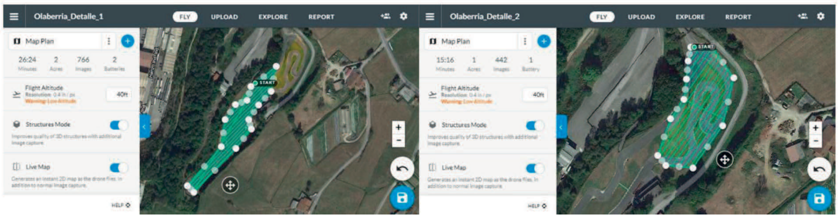

Fig. 5.a - (Left) First-model 61m, Fig. 5.b (Right) Second-model 18.3m

Flight	Precision	Resolution	Time (minutes)	Number of pictures	
61m	242mm/px	16,7mm/px	9.36	169	1st model
18,3m	72,5mm/px	5mm/px	10.12	190	2nd model
12,3m	50mm/px	3,4mm/px	(partial)		
12,3m	50mm/px	3,4mm/px	15:16	442	3rdmodel
			26.24	766	3rd model

Table 2: Flight data

connecting the inputs and outputs of the actuators with the driver's actions in a simple way.

The following image (Fig. 8) shows the final image of the car designed in Tecnun's Formula Student and the Vilariño track in the CRUDEN Simulator.

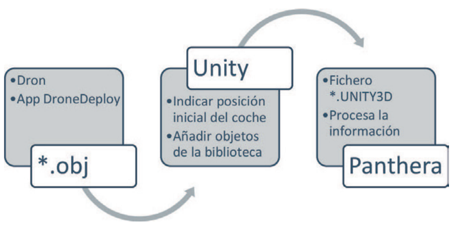

Fig. 7: Workflow

4. DISCUSSION AND CONCLUSIONS

The main objective of this work was to study the most suitable low-cost method for modelling the Vilariño Motorsport (Olaberria) race circuit that could be integrated into the CRUDEN simulator, currently located in the at the Automotive Intelligence Center - AIC located in Amorebieta, Basque Country, Spain.

The achievements are the following ones:

1. A 3D model of the Vilariño Motorsport (Olaberria) racing circuit -used by the Tecnun-University of Navarra Formula Student team- using aerial photogrammetry with drones, and a reference for future modeling of other tracks.
2. The use of a low-cost procedure, both in investment of equipment and in time.
3. An accuracy in 3D terrain modeling of 50mm / px and a resolution of 0.4in / px (10mm / px)
4. The integration of the 3D model in the CRUDEN simulator used by the AIC in such a way that it interacts with the mathematical model of the Formula Student car, previously introduced in the simulator.

The track has been modelled using photogrammetric capture by a drone and its subsequent post-processing. This has been carried out by means of aerial photogrammetry, in which the point of view is mobile and provides a wide range of uptake. Although neither the position of the camera nor its orientation is known at the time of shooting, the technology and the digitalization of the processes allow solving these problems. For this purpose, the following steps have been taken: 1) Taking pictures of the terrain: a flight planning and picture taking were carried out, 2) Image processing: Once the pictures were obtained, they were processed obtaining the DTM model, and 3) Orientation of the images: The frames should be placed in the appropriate position and in the same position as the picture shooting order. To reconstruct and form the model, two systems can be chosen: by restitution or by rectification. When doing it by restitution, the turns, transfers and scales are applied. In this way, a terrain coordinate model is obtained and the scaling of the object is included to work with real measurements. In the case of rectification, after the orientation of the light beam (internal and external), the intersection between that light and the digital terrain model (MDT) is achieved.

The final model achieves a resolution of 3.4mm / px and a maximum error of 50mm, which is an adequate precision for the simulation. The available topographic alternatives have an error of approximately 1 m and 1 mm if using specialized equipment. The drone used costs 100 times less than the LIDAR required for maximum precision. This method, in addition, allows modeling the track in less than 1 day, while the other methods need at least a week.

This 3D model has been incorporated into the Unity program, a free software, and later integrated into the CRUDEN simulator, in collaboration with the Automotive Intelligence Center - AIC. The work has been carried out within the Tecnun Formula Student project framework.

The simulator facilitates considering the human component in the calculations, as well as the circuit lap time, which is extremely interesting. The importance of simulators is that their use in the vehicle design phase is highly beneficial (mainly due to the lower costs associated with prototype construction) for vehicle development.

The future development lines would be: 1) Correlation of the simulator test with real track test, 2) Correlation of the simulator test with test done using the IPG-CarMaker driver model, 3) Improvements in the circuit modelling, flying at a lower height for greater definition. 4) Comparison of race line differences between human driver and IPG Race driver model.

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