The CLEANDRIVE Project (sponsored by FCT – Fundação para a Ciência e Tecnologia) has the objective of developing an innovative and educational driving simulator, making use of a state-of-the-art man-machine graphic interface and a patented software that calculates the vehicle dynamic, fuel consumption and pollutant emissions.

This driving simulator focuses also in promoting a safe and environmentally friendly driving behaviour. In opposition to common simulation games, CLEANDRIVE adopts pedagogical tools regarding the rules, the scoring method and the visual interface to promote a safe and environmental friendly driving behaviour (eco-game). Thus, the ‘player’ will not score if he/she is the first finishing the game but rather if his/her behaviour protects the environment and encourages the safe driving. To achieve this purpose, CLEANDRIVE estimates in real time the pollutant emissions and the fuel consumption, depending on the driver behaviour; at the same time, it accounts the driver’s traffic offences and incorrect behavior.

In order to guarantee a realistic visual interface, the research group DIGRASYS (Distributed Interactive Graphic Systems from INESC-ID) is making use of real-time rendering software tools and three-dimensional physical models. Thus, it is expected that the player feels like being in a real vehicle and behaving as drivers do. The pollutant emissions will be estimated by the computational model ECODRIVE, developed in the framework of a project sponsored by Fundação para a Ciência e Tecnologia. This computational model calculates, for conventional and alternative propulsion technologies, the fuel consumption and the emission of Unburned Hydrocarbons, Carbon Monoxide (CO), Nitrogen Oxides (NOx), Carbon Dioxide (CO₂) – the main anthropogenic green house gas – and particulate matter (PM). In addition a physical support is being built which will include not only the computer equipment but also the sound and video systems and a group of commands (steering wheel and the pedals) which will promote a more natural and real driving.

Keywords: Driving Simulator, Environmental Education, Sustainable Mobility.

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CLEANDRIVE – A SAFE AND ENVIRONMENTALLY FRIENDLY DRIVING SIMULATOR

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Abstract The CLEANDRIVE Project has the objective of developing an innovative and educational driving simulator that integrates the dynamic driving experience with real-time calculations for fuel consumption and pollutant emissions. While focusing on promoting a safe and environmental friendly driving behaviour the simulator also allows the user to make contact with new technologies such as alternative fuels (biodiesel, ethanol, etc). In opposition to common simulation games, CLEANDRIVE adopts pedagogical tools regarding the rules and the scoring method. To achieve this purpose, CLEANDRIVE estimates in real time the pollutant emissions and the fuel consumption, depending on the driver behaviour; at the same time, it accounts the driver’s traffic offences and it incorrect behaviour. In order to guarantee a realistic visual interface it was developed real-time rendering software tools and three-dimensional physical models. In addiction a physical support was built which includes not only the computer equipment but also the sound and video systems and a group of commands (steering wheel and the pedals) which promotes a more natural and real driving.

Key-Words Driving Simulator, Environmental Education, Sustainable Mobility, Alternative Fuels, 3D Rendering, Physics simulation.

INTRODUCTION
The transport sector is among the fastest growing economic sector, as the movement of people and good trades have increased during the last decades. Thereby it is notably the increasing pressure on the environment and on natural resources. In fact, the transport sector is almost exclusively dependable on fossil

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resources (96.4%), being responsible for 66.8% of the worldwide petrol consumption [1]. At the same time, the transport sector contributed to 25% of all the world anthropogenic carbon dioxide emissions (CO₂) released into the atmosphere and approximately 84% of those emissions are from road transport [2]. Renewable fuels, such as ethanol, biodiesel and biogas, are identified as one of the main short-term solutions to reduce the transport sector oil dependency, to decrease the GHG emissions and fully accomplish the Kyoto Protocol targets [3]. Additionally, in order to promote the use of biofuels for transports the European Union, supported by the Directive 2003/30/CE, has established the target of introducing a minimum proportion of 5.75% biofuels or other renewable fuels in the European market by the end of 2010.

The CLEANDRIVE Project (sponsored by FCT – Fundação para a Ciência e Tecnologia) developed an innovative and educational driving simulator that calculates in real time the vehicle dynamics, fuel consumption and pollutant emissions, stressing the advantages of using renewable fuels as an alternative to conventional ones while also improving driver awareness of how its behaviour influences not only the safety of a trip but also its environmental impact. Its added value, which makes this simulator a unique tool, is its ability of merging the eco-game philosophy and its pedagogical goals with a creative and realistic visual interface. Indeed, CLEANDRIVE focuses on promoting a safe and environmental friendly driving behaviour. In opposition to common simulation games, CLEANDRIVE adopts pedagogical tools regarding the rules, the scoring method and the visual interface to promote a safe and environmental friendly driving behaviour. Thus, the ‘player’ will not score if he/she is the first finishing the game but rather if his/her behaviour protects the environment and encourages the safe driving.

Moreover, in order to guarantee a realistic visual interface, CLEANDRIVE uses tools of real-time rendering software and three-dimensional physical models, as it is expected that the player feels like being in a real vehicle and behaving as drivers do.

CLEANDRIVE SYSTEM OVERVIEW

The development of the simulator is a complex task as it involves the cooperation of the different specialties.

In first place, there is the requirement that the simulator is visually attractive, provides a satisfactory experience and is user friendly in order not to distract the
user from the main objective of a safe and environmental driving. Taking this into account, a realistic graphic interface was developed – Figure 1. A graphical environment was specifically developed for this project by DIGraSys (Distributed Interactive Graphic Systems), a INESC-ID research group. It displays custom made cars, trees, traffic signals, houses, bus stops and other regular day life objects – see also Annex 1. In order to visualise ecologic messages, custom made environmental friendly elements, such as recycle and ecological publicity panels, were implemented. In terms of weather conditions, the simulator is capable of representing fog, clear day, and day/night cycle situations.

![Figure 1 – CleanDrive main simulation screen](image)

In second place, the simulator should feature real physics and environmental simulation. The car physics simulation and 3D object interaction, such as collisions, are supported by PhysX, a commercial physics engine from Ageia company [12].
The information provided on the environmental impact of the drive needs to be as reliable as possible, provide consistent information for fuel consumption and pollutant emissions and cover the different technologies and fuels available. For this purpose, a numerical environmental model was developed by using information from both manufacturers and simulation models. The environmental and energy analysis was performed by the IST research group DTEA (Transports, energy and Environment). This way, each car has its own and specific engine behaviour described by custom parameters, such as torque curve, max rpm and min rpm. All the information regarding the fuel consumption and pollutant emissions are displayed in real-time in the Head-Up Display (HUD) section of the CleanDrive main simulation screen (see figure 1).

In terms of logic of the game, as said before, the user must play in a way that his/her behaviour protects the environment and encourages the safe driving. The driver must pay attention to speed limits, traffic lights and all general driving rules, because each infraction invokes a specially chosen message according to the situation. The driving sessions are limited by a chosen time, specific for each level. If the user is driving a bus, an extra goal is required: picking up passengers at the bus stop. Another valuable aspect of the system concerns the existence of non-playable vehicles which are controlled by artificial intelligence.

It’s also possible to create new fully customized levels using a level-editor tool developed specifically for this project. This tool allows the user to manage all the assets available on the project: to create new tracks with specific properties (e.g., speed limit, crosswalks, crossings, etc.) and fill them with buildings, trees and daily life street elements (e.g., street lamps, traffic lights, signals, posters, etc.).

CLEANDRIVE SYSTEM ARCHITECTURE

CleanDrive runs on a 3D graphic environment with all the common elements that the player can find in day life. The system features physical and ecological simulation, offering to the player valuable information about current driving and respective pollution produced by the vehicle.

According to the figure 2, CleanDrive architecture is divided into 7 modules: **Main Simulation Loop Module, Player Input Module, Graphics Module, Simulation AI Module, Simulation Logic Module, FrameBuffer To Display and Physics Module.**
Main Simulation Loop Module
In this module, the code execution enters into the main game loop. This is where the action begins and continues until the user exits out of the main loop. It manages the window stuff, where options menus (like player level and vehicle selection) are relevant and supports the basic framework of the system;

Player Input Module
In this module, the player’s input is processed and/or buffered for later use in the AI and Simulation Logic modules. Player input is managed by DirectX [15] which allows obtaining data from external input devices, such as Joystick or keyboard, filtering the data to be integrated in Simulation Logic.

Graphics Module
Graphics module was developed on top of OpenGL [16] graphics library. This module supports realistic graphic visualisation tasks such as: 3D model
rendering, textures, materials, fonts, cameras and Heads Up Display (HUD). It also supports algorithms for speed up rendering like viewing-frustum culling.

**Simulation AI Module**
This module provides support for both Artificial Intelligence and Event Control. Although these are different objects, they work in collaboration for system simulation stability. Artificial Intelligence is responsible for vehicle driving and event tracking.

**Simulation Logic Module**
It gathers the information and data structures from the Graphics, Physics and AI modules to create the content for display rendering.

**Framebuffer To Display**
It receives the processed information from simulation logic in order to display it in the screen.

**Physics Module**
Physics simulation implemented in CleanDrive is supported by PhysX, a commercial physics engine from Ageia company [12]. PhysX is a physics simulation library that provides all the basic and complex real life physics simulation.
It supports the car physics simulation, collisions and other physical objects interaction and environmental simulation – see figure 3.
The numerical environmental and energy model (NEEM), which will be described later, is integrated into the Physics Module of the system architecture and provides the consumption and emission maps which will define the engine behaviour in the car physics simulation.

**Vehicle Physics**
In general terms, a vehicle is a group of heterogeneous components that contribute to the stability and aerodynamics. In simulation activity, the following four parts of the vehicle should be considered:
- Body which concentrates most of the mass of the vehicle. This part should be aerodynamic in order to reduce air resistance. It contains variables like mass, mass center, frontal area and others.
- Engine which is the component responsible to apply torque to the axle in order for the vehicle to move. It contains variables like horsepower, gear
ratio and differential, acceleration, binary curve (RPM function) and RPM for gear up or down (automatic gears).

- Axles which are responsible for the transmission of torque to the wheels, and for the suspension of the vehicle, to determine its behaviour when accelerating, curving or passing a bump on the road.
- Wheels which are the components in contact with the road and should have variables like size, material and others that affect the grip of the wheels.

![Diagram](image)

**Figure 3 – Physics Module in detail**

**Objects physical interaction**
Collisions are arranged in different categories for event tracking. The road model used as world ground floor is split in two models, for event tracking e.g. to detect when the driver steps the sidewalk.

Implemented vehicles structures are encapsulated by a bounding box volume with four or more wheels. This information is very important to collision detection strategy since it reduces physics simulation time.

**NUMERICAL ENVIRONMENTAL AND ENERGY MODEL**

The numerical environmental and energy model (NEEM) computes fuel consumption and pollutant emissions and covers the different technologies and fuels available. The methodology is valid for both light and heavy duty vehicles.
(using conventional and alternative propulsion technologies), and conventional
diesel and gasoline) and alternative (biodiesel, ethanol and biogas) fuels. The
methodology includes estimates on fuel consumption, CO2 emissions and
pollutant emissions (Unburned Hydrocarbons - HC, Carbon Monoxide - CO,
Nitrogen Oxides - NOx and Particulate Matter - PM).
NEEM is integrated into the Physics Module of the system architecture and
provides the consumption and emission maps which will define the engine
behaviour in the physics car physics simulation.

Emissions maps computations
Emissions maps define consumption and emissions (in grams per second) as a
function of engine rpm and load. Results are presented in 10% load and 500 rpm
intervals. These maps are obtained in one of two ways:

Option 1: Directly from the engine manufacturer – the best option but one that is
rarely possible due to the restricted availability and possible use of those maps.

Option 2: The maps are calculated for each vehicle using a sub model of the
EcoGest modelling tool.

The model EcoGest [4] is coded in Visual Basic programming language and is
described with the minimum number of parameters required for a proper
simulation of the reality, allowing an easy use and a simpler calibration process.
Figure 1 presents EcoGest scheme for the calculations.
Model calculations are based on the motor vehicle dynamics in order to
estimate, at each second the engine load and speed. Engine load is obtained
dividing the brake power by the maximum power at the same rotation speed
(rpm). Brake power ($P_b$) is generically obtained from:

$$P_b(t) = \frac{1}{\eta} \left[ \frac{1}{2} \rho_a C_d A_f v^2 + C_r M g \cos(\theta) + M g \sin(\theta) + \left( (C_{ir} - 1) M + M \right) a \right] v + P_{ac}$$

where $\eta$ is the transmission efficiency, $a$ is the vehicle acceleration, $A_f$ is the
vehicle frontal area, $C_d$ is the drag coefficient, $C_r$ is the rolling resistance
coefficient, $C_{ir}$ is the rotational inertia coefficient higher or equal to one, $g$ is the
acceleration due to gravity, $M$ is the loaded vehicle weight, $M_c$ is the vehicle
curb weight, Pac is the average power consumption of vehicle accessories, \(\theta\) is the road grade and \(\rho_a\) is the air density.

Engine speed (\(n\)) is obtained from the instantaneous vehicle speed, selected gear and tire dynamical radius (\(r\)), with \(v\) in m/s, [5]

\[
n = \frac{60 \cdot v \cdot i}{2\pi \cdot r}
\]

where \(i\) is the gear ratio between engine and drive wheels.

With this information (engine load and speed) bilinear interpolation of stationary and fully warm characteristic maps of the engine allows to estimate fuel consumption and engine-out emissions.

In case these maps are unavailable, which is the current situation in the CLEANDRIVE, the map generation sub model is used.

The sub model for the spark ignition engine map generation calculates the hourly fuel consumption through the indicated efficiency definition [6]. The frictional losses are estimated through the Patton et al model [7]. The indicated efficiency is estimated through Wu Wei and Marc Ross methodology [8]. Engine-out emissions and exhaust temperature are estimated as a function of the fuel consumption though experimental correlations (see fig for natural gas). In case of a cold-start or part-warm start some factors concerning friction (oil temperature) and mixture preparation (coolant temperature) are applied to the hot fuel and emissions allowing estimating the cold fuel consumption and engine-out emissions in such situations [9]. The exhaust after treatment sub model [10] allows estimating tailpipe emissions and is based on one-dimensional finite difference analysis of the exhaust pipe and catalytic converter. In other models, like CMEM [11] the catalyst efficiency is represented by parameters fitted to data, while in EcoGest it is calculated from physical principles. An evaluation study of this sub model [10] showed that the catalyst temperatures are predicted with an error typically less than 10% and the conversion efficiencies errors are typically of 6%. CO\(_2\) is calculated proportionally to fuel consumption deducting the CO\(_2\) not formed due to tailpipe HC and CO formation.

**NEEM integration in the system**

Having the engine maps obtained by one of the previous described methods, it is now necessary to integrate them into the Physics Module of the system
architecture. This is necessary not only to calculate fuel consumption and emissions but also to define the torque being applied to the wheels. Three dimensional simulation programs calculate all environmental parameters (both the visual aspect and all the physical correlations) several times per second (typically 60 times per second, but other frequencies can be used). In order to have a proper integration, the environmental model is computed on every cycle. That is processed in the following way (this example is for a vehicle using a manual gearbox):

1. Obtain from the physical model the rotational speed of the traction axis: \( \omega_w \), current gearbox position and respective gear ratio \( Gr \) and throttle position \( Tp \) (also represents engine load).
2. Using the gear ratio calculate engine rotational speed \( \omega_e \):
   \[
   \omega_e = \frac{\omega_w}{Gr}
   \]
3. Using the calculate rpm and throttle position interpolate the values from the consumption and emissions map
4. Using the calculate rpm and the maximum torque curve of the engine used interpolate the maximum torque available at that regime \( MT \)
5. Calculate engine torque \( Te \)
   \[ Te = MT \times Tp \]
6. Using gear ratio calculate torque being applied to wheels \( Tw \)
   \[ Tw = Te \times Gr \]
7. Use calculated torque as input to physical engine with the resulting speed being used in the next cycle

**LEVEL-EDITOR TOOL**
CleanDrive project includes, beyond the simulator, a level-editor tool (Figure 14) to develop custom levels. This editor allows adding standard road components and visual level element fillers. For road components, the editor includes straight roads, crossways, curves, crosswalks and bus stops. As visual
elements, the editor includes trees, houses, road signals, trash cans; paper/glass/plastic/batteries recycle boxes, ads, etc. The editor also allows setting road properties such as top speed, traffic rules and event trigger.

![Figure 14 - Project Editor](image)

**RESULTS**

The following pictures (15 to 17) present a series of screenshots of the simulator under different conditions. At the current level of development the simulator can be used to drive an urban bus using Diesel or natural gas. More vehicles will be introduced as the program is developed.
Figure 15 – Road Signals.

Figure 16 – External Bus View, crosswalk and display warning.
CONCLUSIONS

The CLEANDRIVE Project has the objective of developing an innovative and educational driving simulator that integrates the dynamic driving experience with real-time calculations for fuel consumption and pollutant emissions. The simulator is being developed using a state-of-the-art visual interface and modelling tools for emission calculation. The environmental module of the simulator is prepared for vehicles using conventional and alternative fuels (biodiesel, ethanol, etc). The estimation in real time of the pollutant emissions and the fuel consumption (through the use of a microsimulation model developed by the authors named ECOGEST) complements the analysis of the driver behaviour and the driver’s traffic in order to provide a complete educational simulator.

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ANNEX 1 – CLEANDRIVE VISUAL ELEMENTS

All models were modelled in Blender [14], a public modelling software tool.

Bus
Chassis - 2661 triangles 2038 vertices, 1 texture 1024x1024;
Each Tire - 444 triangles 418 vertices, 1 texture 512x512;

Sports Car
Chassis - 2052 triangles, 1256 triangles, 1 texture 1024x1024;
Each Tire - 297 triangles, 308 faces, 1 texture 512x512;

Standard Vehicle
Chassis - 2172 triangles, 2001 vertices, 1 texture 1024x1024;
Each tire - 618 triangles, 592 vertices, 1 texture 512x512;

Jeep
Chassis - triangles 1884 vertices 1821, 1 texture 1024x1024;
Each tire - 346 triangles, 304 vertices, 1 texture 512x512;
Sample of some level assets – all low polygon (less than 300 triangles), each one with 1 texture 256x256;