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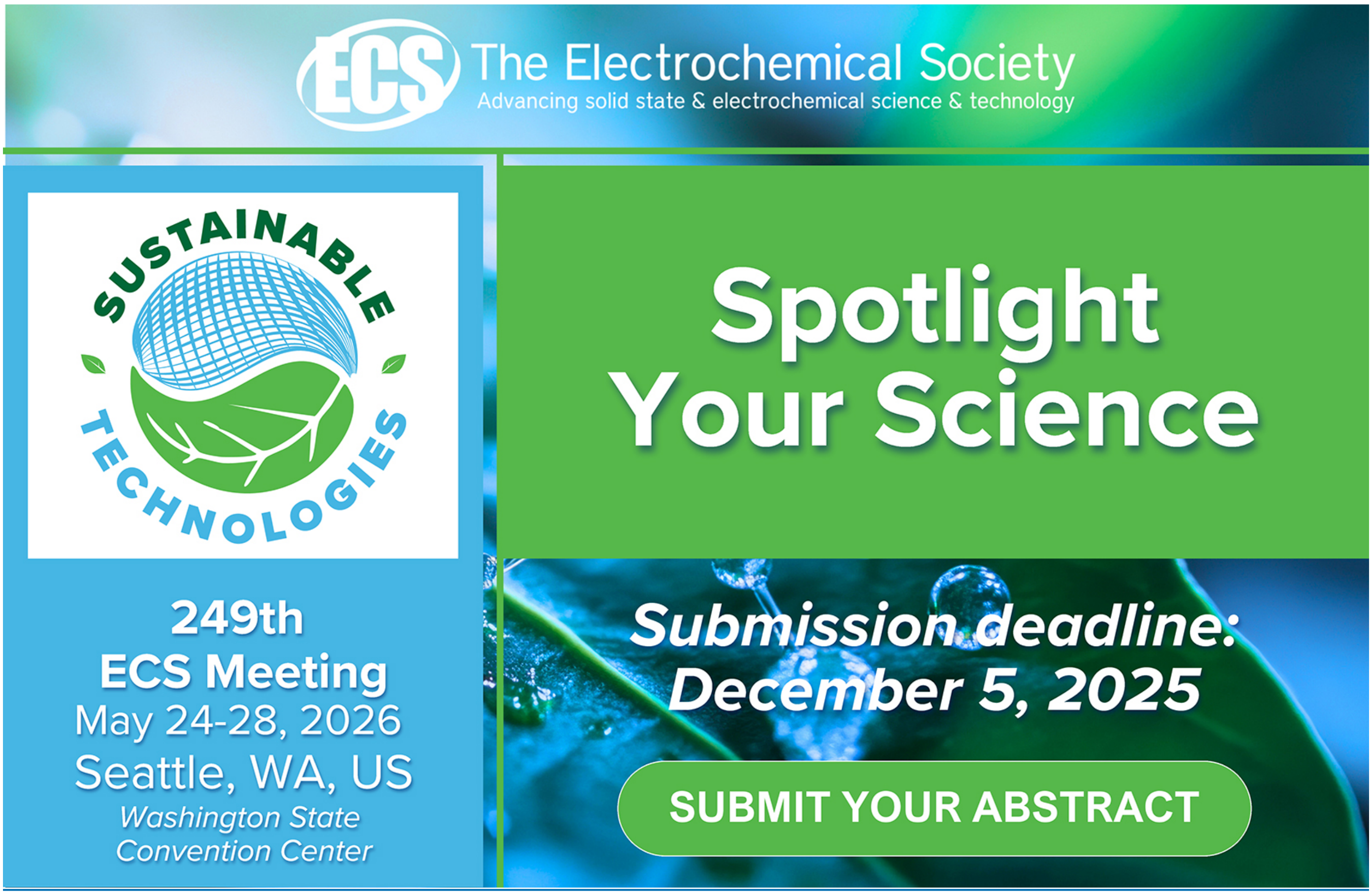

Design of an electric race car digital-twin simulation model and analysis using BeamNG.drive and MATLAB

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Abstract. The Debrecen region is experiencing significant transformation driven by investments in the automotive industry. Reflecting this progress, the Vehicle Research Centre at the University of Debrecen's Faculty of Engineering aims to integrate electric vehicles into the Faculty's activities, aligning with modern trends. To support this initiative, an existing Toyota MR2 owned by the Faculty will be converted to an electric drive vehicle, providing students with opportunities to participate in future car competitions. Given the vehicle's older production model, creating a Digital-Twin model based on its original datasheet was essential for preliminary simulations, which were then adapted to the electric drive configuration. The vehicle model and simulations were developed using BeamNG.drive and MATLAB software.

Keywords: electric race car, BeamNG.drive, vehicle dynamics test, MATLAB, digital-twin

1. Introduction

Global developments in sustainable energy and the electrification of transport are driving the research and development of electric vehicles. Electric propulsion has taken centre stage in both commercial and automotive racing due to its efficiency, low emissions and high performance. This project is about exploring the intricacies of designing, optimising and simulating electric vehicles. The Toyota MR2 used for this project is a lightweight, mid-engined sports car. By converting the vehicle to electric, this study aims to contribute to the use of the conversion in motorsport [1].

The simulation-based approach in this study uses the collaboration of several software for design, testing and analysis. BeamNG.drive [2] is a dynamic simulation platform known for its detailed physics engine that can provide realistic conditions for testing the electric version of the Toyota MR2 [3] under varying driving conditions such as acceleration, cornering and braking situations. Automation [4] software is used to design and configure key vehicle parameters. Providing a comprehensive environment for setting parameters related to the electric powertrain. MATLAB [5] is used for mathematical modelling and performance analysis, allowing precise control of variables such as torque, battery management and energy efficiency.

The Toyota MR2 was chosen as part of a group project provided by the Faculty of Technology of the University of Debrecen. This vehicle is of great importance in the automotive community as it is a great platform for modification and racing, due to its unique handling characteristics due to its mid-engine layout.

By creating the Toyota MR2 and its simulation electric twin, this study aims to provide a solid usable basis for the project and to make the goal more understandable and tangible. Furthermore, it aims to implement designs conceived during brainstorming sessions on a simulation platform, thus providing a cost-effective and reliable way to test ideas.

2. Used programs for vehicle dynamic simulation

From a sustainability perspective, vehicle use is a key factor, as internal combustion vehicles produce significant carbon dioxide emissions, which have an impact on our planet. In order to reduce the effects of climate change, carbon dioxide emissions must be reduced. One possible solution to this is the use of electric vehicles. Another possible solution is to convert existing internal combustion vehicles into electric vehicles.

Since there are many types of cars and each car brand has developed its own unique solutions, a method had to be developed in order to establish a model for converting internal combustion vehicles into electric cars.

The Toyota MR2 owned by the University of Debrecen was chosen, which is currently not operational, but by setting up a suitable simulation model, telemetry data can be extracted, and after conversion, the values can be compared and conclusions drawn.

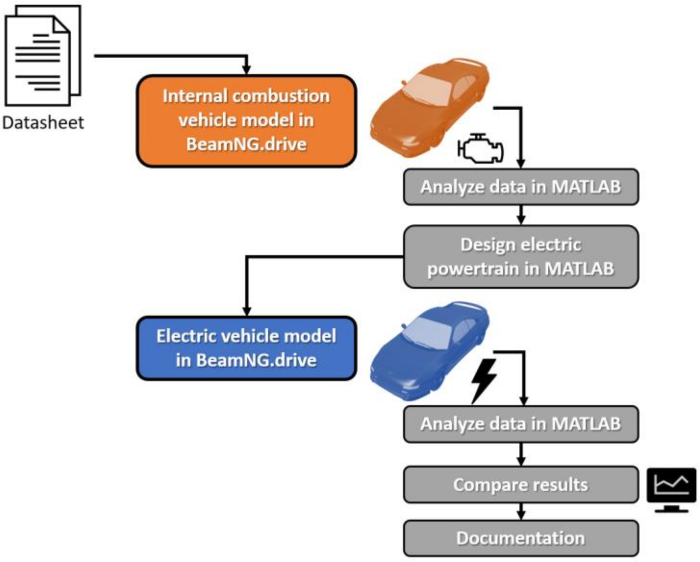

Figure 1. The methodology used to generate telemetry data for vehicle models.

The essence of the methodology developed is that the vehicle model was built in the BeamNG.drive development environment based on the data sheet for the given vehicle type. Subsequently, the virtual vehicle model was run on a test track designed by us. Telemetry data is also generated during the laps and exported. After exporting, the extracted data is processed and analyzed in MATLAB. This provides a reference basis for later conversion of the given vehicle into an electric vehicle based on the already known parameters. The electric vehicle is also built in BeamNG.drive, where the telemetry data is again extracted and processed (see Figure 1).

The project also aims to answer the question of whether the methodology is capable of extracting telemetry data that can be used to build a completely accurate vehicle model.

The Toyota MR2 vehicle is physically inoperable, but before the complete renovation of the vehicle actually begins, an accurate model could provide an answer as to whether it makes sense to renovate and convert such an old vehicle type. The following study seeks to answer this question. The developed methodology has described below. Industry and research are increasingly using simulation platforms to carry out development and research. The key drivers are cost-effectiveness and freedom of choice. To achieve this, it is important to use a suitable simulation platform that provides the necessary physical background to be able to match reality.

BeamNG.drive is a vehicle simulation platform with a decade-long history, available on Windows and Linux [6].

BeamNG.tech provides an outstanding platform among the myriad of simulation platforms. This is due to its custom-developed soft-body physics engine, detailed modelling of vehicle subsystems and high level of customisability. The soft-body physics engine allows for an authentic simulation of the kinematic properties of vehicles. The system also allows full customisation in any situation [7] (see Figure 2).

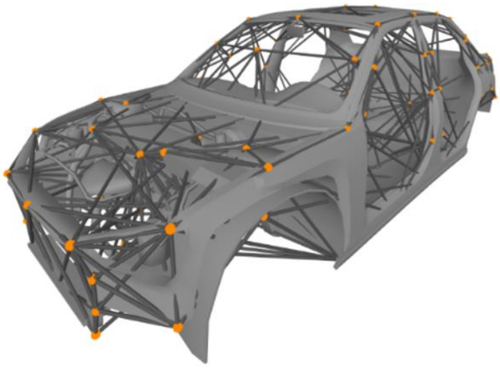

Figure 2. BeamNG.tech node system [7].

The soft-body engine used by BeamNG.drive is a dynamic system, each unique element is deformable. BeamNG.tech [20] achieves this system using a spring-mass model. This way, each element has its own 3D model and a physical skeleton. This allows the study of the full kinematic and dynamic properties of vehicles, since the properties of an entire object are dictated by the state of its constituent elements. This system is built up by springs, beams, and mass points, nodes. The mass points have a coordinate in space which is updated according to the force acting on them. Springs are structural elements, connecting mass points that resist loads, mainly compression and expansion. These springs have lengths that vary according to the forces acting on them, damping the forces according to the coefficients of compression and expansion. These springs have a deformation tolerance, beyond which the spring may break.

$$\boldsymbol{F}_i = m_i \frac{d^2 r_i}{dt^2} \tag{1}$$

where $\boldsymbol{F}_i$ is the total force acting on mass point “i”, m_i is the mass of mass point “i” and r_i is the position of mass point “i”.

The $\boldsymbol{F}_i$ all forces at point "i" can be written as the sum of spring force, damping force and external forces:

$$\boldsymbol{F}_i = \sum_j \left[k_s \left(|\boldsymbol{r}_{ij}| - l_0 \right) \frac{\boldsymbol{r}_{ij}}{|\boldsymbol{r}_{ij}|} + k_d \left(\boldsymbol{v}_i - \boldsymbol{v}_j \right) \right] + \boldsymbol{F}_{external} \tag{2}$$

where k_s is the spring constant, $r_{ij} = r_j - r_i$ is the vector between mass points "i" and "j", l_0 is the rest length of the spring, k_d is the damping coefficient and $\boldsymbol{v}_i$ and $\boldsymbol{v}_j$ are the velocities of mass points "i" and "j".

The physical engine is complemented by a mass-spring-damping model:

$$Fs = -kx - c\dot{x} \tag{3}$$

Where the force Fs is required to stretch or compress the spring by a distance x. The coefficient k is the spring constant. Damping is a force that acts in the opposite direction to the motion of the spring and is part of the velocity of the spring (x) times a c that gives the internal friction of the spring [7].

In addition to BeamNG.drive, its sister program Automation allows you to design and pre-test vehicle engines. Any parameters of the vehicles can be specified by the user, from the chassis structure to the engine architecture.

The vehicle model consists of 3 main components. Appearance, kinematic properties and the propulsion system. Appearance is a typical 3D model, but has a corresponding structural part that gives the physical properties of the vehicle. It is a so-called physical skeleton that defines the interaction of the vehicle with its environment. This includes the propulsion system that moves the vehicle. As part of the 3D model, the drivetrain is not interpreted as it is a unique part of the physical model (see Figure 3). It is a very detailed simulation that monitors the operation of mechanical and electronic components. BeamNG.tech's powertrain system behaves as a plug and play system, so any internal combustion electric motor can be created and used [9].

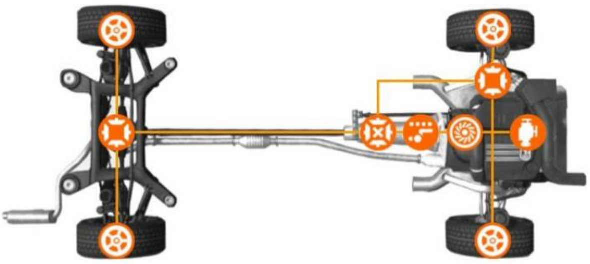

Figure 3. Schematic representation of the vehicle drive train [9].

Data collection is at the forefront of research and development. Situational data collection allows data to be collected in specific configurations [17]. These configurations include traffic, environment and ambient conditions. The system is compatible with MATLAB and Simulink via an additional plugin. This tight coupling between the programs allows to combine MATLAB [18] and Simulink [19] with the advanced BeamNG.tech simulation and analysis environment and evaluate the model specifics [14].

In order to interpret the main movements, it is necessary to know the measurable weight of the vehicle in question [15]. The moments of inertia (Θ) of the masses rotating in proportion to the vehicle speed must be investigated, taking into account the components rotating at different angular velocities (ω) one by one and reducing them to the circumference of the vehicle wheel based on the equivalence of kinetic energy. The kinetic energy of the rotating mass "j" (E_j):

$$E_j = \frac{1}{2}\Theta_j \omega_j^2 \tag{4}$$

Taking into account the angular velocity of the vehicle wheel (ω_k), a reduced moment of inertia (Θ_{jred}) must be added to its moment of inertia, whose kinetic energy, calculated by the angular velocity of the wheel, is equal to E_j:

$$E_j = \frac{1}{2}\Theta_j\omega_j^2 = \frac{1}{2}\Theta_{jred}\omega_k^2 \tag{5}$$

The reduced moment of inertia is given by the following formula:

$$\Theta_{jred} = \left(\frac{\omega_j}{\omega_k}\right)^2 \Theta_j \tag{6}$$

Considering the simplest case of the sum of forces in a plane and in a straight path:

$$\sum F_i = F_v + F_f + F_{ea} \tag{7}$$

Traction force on wheel circumference at constant wheel load:

$$F_v = F_{va} + F_{vs} \tag{8}$$

where F_v is the traction force, F_f is the braking force, F_{ea} is the basic resistance force, F_{va} is the part of the traction force transmitted by adhesion tangential traction and F_{vs} is the part of the traction force transmitted by slip traction.

3. Toyota MR2 and Digital-Twin model design

The Toyota MR2 W1 is a 2-door coupe that is the perfect base for building an electric racing car [21]. It is fitted with a 4A-GE type internal combustion petrol engine with a 1586 cm^3 in-line 4-cylinder construction. The combustion engine drives the rear wheels. The engine has a crankshaft power of 86.5 kW at 6600 rpm and 134 Nm of torque at 4800 rpm. Rated maximum speed is 7300 rpm. Engine bore/stroke 81 x 77 mm, compression ratio 9.4:1, DOHC (Dual OverHead Cam). Total car weight 1090kg. Front suspension independent McPherson, rear suspension McPherson. Front disc brakes are cooled disc brakes, rear solid disc. Steering is hydraulic power steering [8] (see Figure 4). Using this data, a model of the vehicle was created in the Automation program [16].

Figure 4. Toyota MR2 W1 [8].

It is important to find the exact factory parameters and data in order to create a completely realistic replica of the car. As it is an early sports car, all the necessary data is available to start the recreation of the car.

The engine designer part of the Automation design software provides a good basis for building a car. It is very complex to use, especially for engines.

When modeling the vehicle, it was necessary to take into account that BeamNG.drive uses a so-called soft-body simulation, which is suitable for the development of cyber-physical systems (CPS). Numerous source materials are available on this topic, which serve as reference points for the project [10].

The first step was to build a 4-cylinder in-line engine. The material of the engine block was chosen to be cast iron, based on sources. The bore/thrust force was also set to the original 81 x 77 mm. The control type was chosen to be DOHC, the cylinder head material is also cast iron [8]. The engine does not have a separate integral harmonic balancer or balancer shaft. The mass of the balancer on the crankshaft is 3.9 kg [10]. Engine compression ratio is set to 9.4:1. The rated speed of the motor is set to 7300 rpm. The engine does not have supercharging or mechanical overload, so the naturally aspirated engine setting is selected here [11]. The 4A-GE engine and digital twin model are shown in Figure 5.

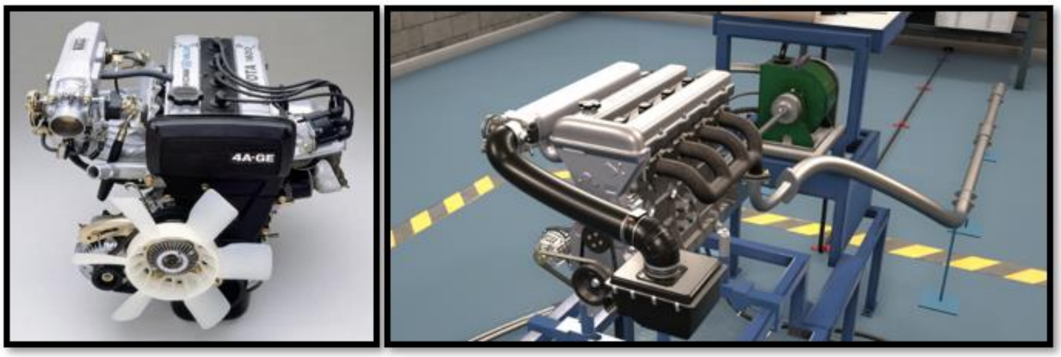

Figure 5. 4A-GE Motor [11] and Digital-Twin Model.

The fuel system of the 4A-GE engine is injected into suction ports upstream of the intake valve. The intake manifold is sized so that the intake air flow is 0.136kg/s. The fuel used for operation is set to unleaded 95 octane gasoline [11]. The exhaust gas flow rate is set to 0.207 kg/s. Exhaust pipe diameter is 50.8 mm. Catalytic converter not fitted at the factory.

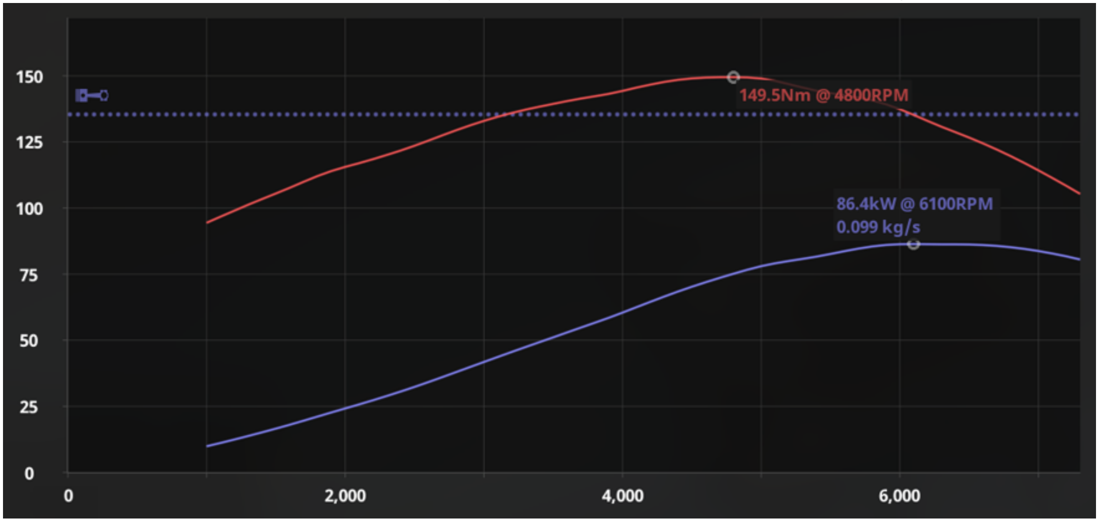

Figure 6. Engine Digital-Twin power curve in simulation.

The engine power curve may differ from reality. The dashed blue line indicates the nominal maximum torque. There the motor will regulate down, but theoretically the motor is capable of higher torque output (see Figure 6).

After the engine was built, the rest of the vehicle was built. The body panels are made of metal and the body type is monocoque. The bodywork is also made of metal. Here, moreover, the positioning of the engine was chosen as a cross mid-engine. The suspension is independent McPherson at the front and McPherson at the rear [11].

The vehicle's manual 5-speed gearbox is fitted with the factory-specified gear ratio.

- 1st gear ratio: 2.4 maximum speed in gear: 71 km/h
- 2nd gear ratio: 1.66 maximum speed in gear: 103 km/h
- 3rd gear ratio: 1.14 maximum speed in gear: 150 km/h

- 4th gear ratio: 0.84 maximum speed in gear: 206 km/h
- 5th gear ratio: 0.65 maximum speed in gear: 266 km/h
- Final gear ratio: 4.64

The vehicle is fitted with an open differential at the factory. The tyres are factory fitted at 185/60 R14 90V. The tyres are of the radial medium hardness type and the rim material is metal.

Front brake disc type cooled 1-piston 250 mm diameter disc brake. Rear brake discs are solid 1-piston 240 mm diameter disc brakes. Brake pads type is set to standard type. This gives a braking force of 4000 N tested for a front brake and 3700 N tested for a rear brake. 44 m are required to stop from 100 km/h in the case of emergency braking [8].

Gear coupled with hydraulic rack and pinion. It is not equipped with a driving assistance system, so I do not install ABS or TCS [8].

It is necessary to adjust the wheel tilt, which is -1.5° at the front and -1° at the rear. I leave wheel lock at 0°. Front suspension spring constant 2.2, rear suspension 3.6. Coefficient of articulation 1.8 for front suspension, 2.6 for rear suspension. The recreated Toyota MR2 Digital-Twin model can be seen in Figure 7.

Figure 7. Recreated Toyota MR2 Digital-Twin model.

To test the Digital Twin model, the data had to be calculated in advance, which required exporting the 3D model along with all calibrated parameters. Then, a unique test track was designed, where the Toyota MR2 completed virtual laps (see Figure 8). The resulting telemetric data was then processed and plotted using MATLAB.

The vehicle model was exported with all its parameters using the built-in export menu. This made the finished vehicle available for testing in BeamNG.drive. The test procedure is to accelerate the original and the modified car from a stationary position to 100 km/h and from there to a stop with emergency braking.

As there will be two Toyota MR2s, one factory-built and one electric version, to be compared, both vehicles will be driven around a track under the same conditions, providing enough telemetry data to interpret the vehicle's driving dynamics.

Figure 8. A track for testing vehicle dynamics.

4. Digital-Twin test and data analyzation

The BeamNG.drive software provides integrated support for MATLAB and Simulink, so the results were compared and the planned modifications were evaluated in terms of their impact on vehicle dynamics.

All tests will be performed at 8:52 simulation time, in sunny weather and calm. The ambient air temperature is constant at 25°C. The gravitational acceleration is 9.81 m/s^2. The asphalt of the acceleration and emergency braking track and the track used for vehicle dynamics testing has a coefficient of adhesion friction of 0.98 and a coefficient of sliding friction of 0.70.

The test will start with acceleration from a stationary position to 100 km/h followed by emergency braking.

The engine load and speed chart can be seen in Figure 9.

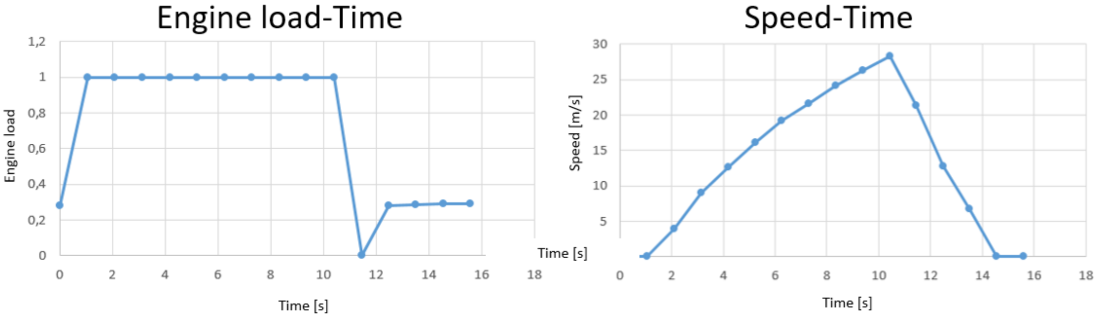

Figure 9. Engine load and speed chart.

The car accelerates from a standstill to 100 km/h or 27.77 m/s in 8.64 seconds, which is in line with the official figures published by Toyota. Furthermore, it can be read that the car comes to a standstill from 100 km/h in 3.8 seconds, which is 44 meters, which corresponds to the official data published by Toyota [8].

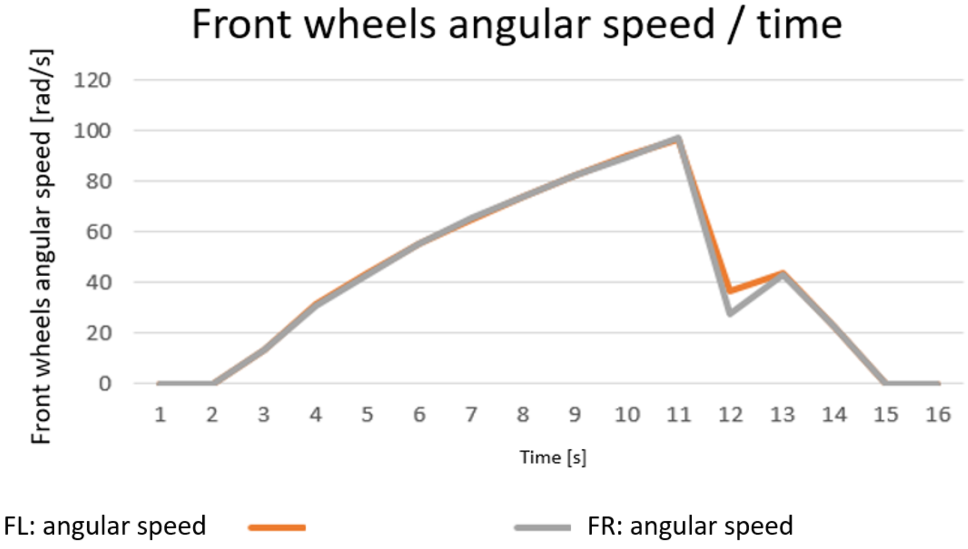

Figure 10. Angular speed of the front wheels.

Figure 9 shows that in the acceleration phase, the front wheels without drive move at approximately the same angular velocity. Between 12 and 14 seconds after the start of braking, it is clear that the front wheels are locked. As the angular velocity drops in both cases, it accelerates back. Furthermore, it can be seen that the left wheel blocking was more significant, as it decelerates up to 27.6 rad/s, even as the right wheel decelerates to 36.35 rad/s. This phenomenon will stop at the 14th second and the wheels will grip again and continue to decelerate.

5. Digital-Twin Toyota MR2 electric

The chassis and body will remain in factory condition during the conversion. The body panels will be made of fibreglass plastic panels instead of the original metal. This material is a good choice because of its durability and flexibility, and is significantly lighter than metal, so a significant weight reduction can be achieved. Fibreglass is corrosion resistant and is more cost-effective to manufacture with a small number of elements.

The original McPherson suspension was replaced with a pushrod swingarm suspension. This will significantly improve suspension and damping. It will also provide more space for wider wheels. The vehicle suspension of the virtual vehiclecan be seen in Figure 11.

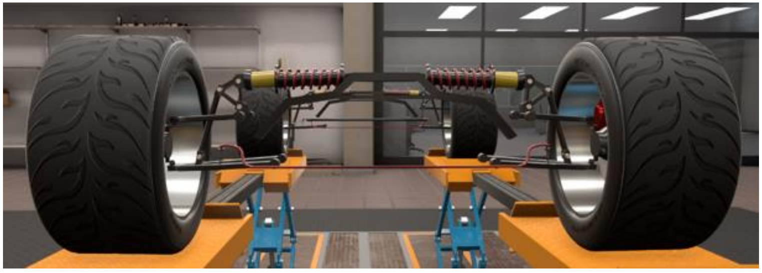

Figure 11. Vehicle suspension of the virtual vehicle.

The electric motor to be installed is an EMRAX 268 type electric motor, whose official technical data is as follows:

- Peak power: 230 kW
- Peak torque: 500 Nm
- Weight: 20.3 kg
- Electric motor efficiency: 92-98%
- Diameter and width: 268/91 mm [13].

The installation of a single-speed gearbox is important because the output speed of the electric motor is significantly higher than the speed at which the wheels can rotate. It is also important that the motor can deliver the torque required. To do this, the desired final speed had to be determined, which was set at 165 km/h.

The gear ratio (i):

$$i = \frac{n_e}{n_w} \tag{9}$$

where n_e is the engine speed, and the wheel speed (n_w) takes into account the value required for the vehicle's final speed:

$$n_w = \frac{n_{top}}{\pi \cdot 2R} \tag{10}$$

Where the top speed (n_{top}) is 45.83 m/s and the wheel diameter ($2R$), with 305/35 R15 tyres, is 0.594 m. Thus the wheel speed is 24.55 1/s. Peak engine power is delivered at 5500 rpm, corresponding to 91.6 1/s. Thus the required gear ratio is calculated:

$$i = \frac{91.6}{24.55} = 3.73 \tag{11}$$

With this gear ratio, the electric motor will be able to maintain its peak power over a wider range, improving the acceleration of the vehicle. In addition, to further improve driving dynamics, a limited-slip differential is needed to deliver more power to the more traction-holding wheels.

Some modifications to the bodywork were necessary. One of these is the widening of the fender arches, as the wheel chosen for the vehicle is significantly wider than the original. In order to prevent the wheels from rubbing against the mudguard arches, the mudguards had to be moved 5 cm further out. In addition, more air deflectors have been added to the modell to generate downforce. This generates a downforce of 15 kg on the front axle and 29 kg on the rear axle of the car at 100 km/h. Furthermore, with the aerodynamic modifications, the power required to overcome drag is 5.2 kW and 1.9 kW for rolling resistance at 100 km/h. Air ducts for proper brake cooling and air ducts for cooling the electric motor have also been added. In addition, smaller rear-view mirrors have been fitted.

The details of the brake and braking system modification are as follows:
- Front brake diameter: 285 mm, floating single-piston caliper
- Rear brake diameter: 278 mm, floating single-piston caliper
- Ceramic brake pads
- ABS system.

With these parameters set, the predicted braking force is 6200N on the front axle and 4000N on the rear axle.

When adjusting the suspension, you set up sport springs for firmer ride characteristics. The wheel camber angle has been set to -2.5° on the front axle and -1° on the rear axle, thereby increasing the tire contact patch when cornering. The spring rate of the springs on the front axle is 3.20 and 5.60 on the rear axle. The reason for the stiffer springs on the rear axle is that the mass distribution places 60% of the vehicle's mass on the rear axle. The damping constant is 3.40 on the front axle and 5.40 on the rear axle. The damping constant determines how quickly the springs damp. The vehicle belly height is set to 215 mm.

6. Comparison between an original vehicle and an electric racing car

The telemetry data of the two Digital-Twin were compared in order to get a more accurate picture of its effects on the vehicle.

Original Toyota MR2 - Digital-Twin:
- Power: 86 kW Engine torque: 134 Nm
- Vehicle mass: 1090 kg
- Frontal area: 0.417 m2
- Drag coefficient: 0.33
- McPherson suspension
- 5-speed manual transmission, open differential
- Metal monocoque chassis, metal body
- Tyres: 185/60R15 90V
- Front brake: 252 mm 1-piston ventilated disc
- Rear brake: 240 mm 1-piston solid disc
- Weight distribution: 42.5% front, 57.5% rear

Electric Toyota MR2 - Digital-Twin:
- Power: 230 kW Engine torque: 500Nm

- Vehicle mass: 954 kg
- Frontal area: 0.4 m^2
- Drag coefficient: 0.286
- Suspension: 0.5 kg
- Single-speed gearbox, limited slip differential
- Metal monocoque chassis, fibreglass body
- Tyres: 305/35R15 101L
- Front brake: 285 mm 1-piston ventilated disc
- Rear brake: 278 mm 1-piston solid disc
- Weight distribution: 40% front, 60% rear

Acceleration and braking

The original Toyota MR2 accelerates up to 27.77 m/s in 8.64 seconds and then comes to a stop with emergency braking in 3.8 seconds, a distance of 44 meters. Its front brakes apply a braking force of 4000N and its rear brakes 3700N. The electric racing car accelerates to 27.77 m/s in 4.64 seconds and stops in 2.2 seconds, equivalent to 29 metres. The electric racing car's modified front brakes apply 6200N and rear brakes 4000N of braking force, and also uses 25% of the electric motor's braking force for braking on the rear axle. In addition, the electric racing car will be equipped with an aftermarket ABS system, so the likelihood of wheel lock-up during braking will be reduced and braking efficiency will be improved. The original car's 1586 cm3 internal combustion petrol engine produces 86 kW of power and 134 Nm of torque, while the electric motor provides 230 kW of power and 500 Nm of torque.

In acceleration, wider tyres mean that the electric racing car can use significantly more power, and the power curve of electric motors means that they can peak power over a much wider range and at much earlier revs. With the original car's 5-speed manual gearbox, the speed of 27.77 m/s can be reached in second gear, so there is a time loss due to gear changes. In contrast, with the electric car's single-speed gearbox, which is designed with the desired power and top speed in mind, no gear change is required and the electric motor is able to operate in the optimum power range during acceleration. Due to the open differential of the original car, a driven wheel may spin out at the moment of start-up, slowing acceleration until the power distribution between the driven wheels is restored. The electric racing car's limited slip differential ensures that wasted power from spinning wheels is transferred to the wheel with the right grip, reducing the resulting losses and further improving start-up and acceleration. These modifications led to the electric vehicle performing significantly better than the original internal combustion version in this test (see Figure 12).

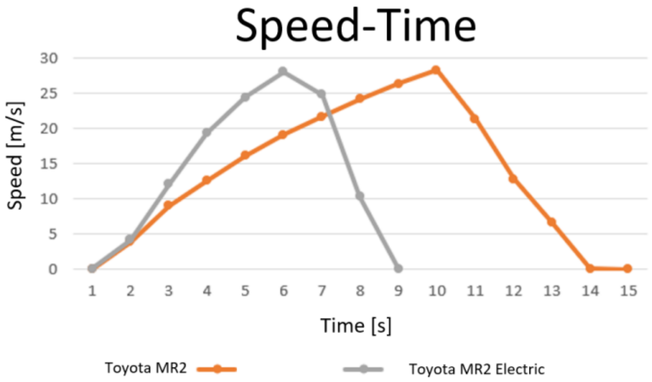

Figure 12. Acceleration and braking comparison chart.

The original Toyota MR2 completes the test track in 49 seconds. Its top speed around the track is 24.32 m/s. The electric racing car completes the test track in 39 seconds and has a top speed of 30.24 m/s. The speed comparison around the test track results can be seen in Figure 13.

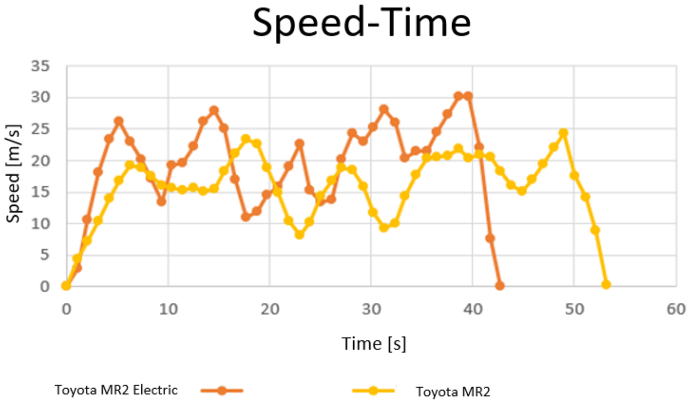

Figure 13. Speed comparison around the test track.

Comparing the curves of the two vehicles, it is clear that the electric car accelerates and brakes more aggressively. The average speed around the track is 15.42 m/s for the original car, compared to 19.8 m/s for the electric car. Analysing the graph, it can be seen that the electric racing car can maintain much higher speeds during cornering and leaves them at much higher speeds. Furthermore, the original car has to make much longer braking distances in order to start cornering at the correct speed, despite the fact that it is travelling around the track at a lower speed than its electric counterpart. The weight distribution of the original vehicle makes it prone to oversteer, which, combined with the open differential, makes it much more difficult to control in racing conditions.

The electric racing car is also prone to oversteer due to its weight distribution, but the limited slip differential significantly reduces the chance of oversteer. Suitable semi-slick tyres, which are significantly wider than the narrower tyres of the original vehicle, will provide much more grip and make the electric racing car more controllable. The chassis of the race car is finely tuned for racing, making it much more stable under load and when cornering. The adjusted tyre camber gives the car more tyre contact patch during cornering, providing grip at the cornering apex. It is also important to compare the two vehicles in terms of drivability, although this is subjective, but it is necessary to know which vehicle gives the driver feedback and how predictable and responsive its behaviour is. The body of the vehicle is basically a perfect basis, as its size makes its behaviour very recognisable.

Its characteristics are predictable and easy to react to. It can adapt to the performance of the original vehicle. The modified electric race car, on the other hand, provides the driver with perfect feedback and therefore a more predictable and confident basis for race handling. The characteristic curve of the electric motor means that the power provided by the motor is well manageable. The single-speed gearbox means there is no need to shift gears in race conditions, so you can concentrate on driving to the full.

7. The impact of vehicle simulation on digital education

The developed method has a significant impact on digital education for enginnering students. It provides an opportunity for automotive engineers to learn about various vehicle types and their structure in detail during their training. Tests can be carried out freely and without restrictions on a digital twin model of a created vehicle. A given vehicle can be fine-tuned by changing its factory parameters, but poorly chosen parameters can even lead to the destruction of the physical vehicle, a danger that does not exist with the digital model. Furthermore, it is also possible to replace individual parts virtually. After preliminary tests, it is also possible to test the modified vehicle on a custom-designed track. In fact, it is even possible to change the actual structure of the vehicle, which can lead to different results during evaluation.

The method is cost-effective, as it is not required to have the physical vehicle under examination. Furthermore, up to 20-30 enginnering students can experiment on a virtual model at the same time, provided they have the necessary files. When assembling a physical vehicle, it would not be possible to involve so many students in the tasks. At the same time, it is also possible to design a completely unique vehicle, which opens up further opportunities for students, allowing room for digital innovation.

8. Conclusion

Building and analysing a simulation model of a vehicle is a complex engineering task that requires specialised software and thorough analytical skills. A Digital Twin model of a Toyota MR2 owned by the University of Debrecen was designed to allow testing in a virtual environment before preliminary modifications.

It is important to note that, as the vehicle under investigation is currently physically inoperable, there is no accurate basis for comparison with the original vehicle. However, the vehicle's datasheet was available at the time the digital twin was created. A digital model can indeed be created by entering the parameters contained in the documents. However, the extent to which the given software environment is able to handle these parameters depends largely on BeamNG.drive. The program is constantly being developed, so it is possible that earlier or later versions may produce different results. BeamNG.drive's soft-body physics engine makes it possible to build a detailed model, but this depends largely on the available parameters and the level of detail of the 3D CAD model. In addition, the development environment is currently less capable of handling weather-related simulations that also affect the vehicle.

The virtually created vehicle model included the design of the chassis, the modeling of the bodywork, the design of the internal combustion engine, and an understanding of the entire structure of the vehicle.

The simulation process was carried out using BeamNG.drive and its MATLAB add-on, which provided visual feedback to make the vehicle dynamics analysis more understandable and tangible. The program allowed for extensive data collection, allowing me to get an accurate picture of the vehicle behaviour in different situations by analysing the telemetric data.

The simulation of the Toyota MR2 model allowed the team to better understand the starting point for building an electric car. And the electric model produced serves as a guide for the project, which can be modified and tested at any time for new ideas or developments. This not only gives flexibility to the project, but also facilitates cost-effective and reliable design.

The role of Automation and BeamNG.drive programmes in industry, education and research is constantly growing. They also play a key role in the development of autonomous vehicles, the improvement and cost-effective testing of self-driving systems. They can also become useful tools in education, in addition to driver training in engineering courses, contributing to the wider professional development of engineers. These tools will remain relevant in the long term and can further help technological innovation.

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