Vehicle Dynamic Development and System Analysis Project

Tamás Szakács and András B. Frigyik

Öbuda University
Bárány Donát Faculty of Mechanical and Safety engineering
Institute of mechatronics and vehicle engineering
E-mail: szakacs.tamas@bgk.uni-obuda.hu, frigyik.andras@bgk.uni-obuda.hu

Abstract. The Vehicle Construction Laboratory of the Öbuda University has been funded to develop Shell EcoMaraton, Bosch GoKart, Bosch Electromobile, Emerson Pneubobile, and Formula Student Hungary project cars. Some international cooperation, based on the European Commission’s Erasmus+ program, has already taken place in the lab. In the year 2021 a mixed team of Hungarian, and international students (participants of the Stipendium Hungaricum scholarship program) started to work on a project related to Vehicle Dynamic. The scope of the project is to develop a test car, that can be driven in a conventional way or capable of autonomous operation. The short range goals are the following: to build a car, with electric driving and steering capabilities, and to work out the system scheme of sensor, controller, and actuator network, for system development, mathematical analysis, and modelling/simulation.

1. Introduction

The goal of this paper is to present the initial of the student project. Internationalization of Emerson Pneumobil competition has started already in the second year of the competition series, and grew quickly. In the recent years approximately 50 teams are signing up from 9, mostly EU countries. There has been effort taken to involve further-EU (Finland, Germany), and non-EU countries as well, like Serbia, Montenegro, South-Korea and Turkey.

In 2021 a group of team was formed from English mechatronic students mixed from Hungarian, and Stipendium Hungaricum students within the frame of English Vehicle dynamic subject. This project involves further students from non-EU countries. At this point students are developing a concept car to develop electric vehicle protrusion, and vehicle stability control systems, but later in year 2022 they are planned to work on Pneumobile project too.

Until less than two decades ago, the primary focus was on using electric motors in Formula E cars only. Today these engines are used on various types of vehicles. These engines are essential for autonomous vehicles to carry out automated tasks due to the ease of control over them compared to internal combustion engines.

These engines provide the kart with a driving experience similar to Formula One, allowing young individuals interested in this F1 racing field the possibility of a similar platform. Therefore, when replacing internal combustion engines with electric motors, care must be taken to provide similar performance to the previous vehicle and mainly safety.

Charles Jeantud electric car offered excellent performance in the Paris-Bordeaux-Paris race, but the 950 kg batteries did not support delivering a driving experience for a reasonable
time. The main barrier of using electric actuators previously was the energy-storing method. This problem prevented this technology from seeing the light despite the actual improvement for both batteries and engines volume over the years. Despite the tremendous technological development that has allowed this technology to be widely used, many drivers still prefer the classic driving approaches. In December 2020, the American research department and advocacy division published consumer interest and knowledge of electric vehicles survey results. This survey showed that only 30 per cent of the participants have knowledge about electric vehicles. However, many professional drivers have shown interest in using electric cars, such as Nelson Piquet Jr, who said that “If you care about the fame and flashes the F1 is the best racing series, but equally exciting for racing drivers are competing in Formula E. Formula E was created to boost electric motorsport, but still very few series are purely electric.”

In Section 2 the concept will be introduced, in Section 3 the model structure, and model details will be described and Section 4 shows the modelling of the vehicle body. In the conclusions a brief summary, and outlook can be found.

2. The concept of electric go-kart

One of the most important advantages of changing the previous structure is to provide static stability of the vehicle since the internal consumption motor was located to the right of the kart making the turn manoeuvre to be unstable. Moreover, the BLDC motors have a compact size compared to the internal consumption engine and a better power to weight ratio. The developed kart contains a separate motor that will drive each rear wheel, and two front wheels provide static stability and control the steering. Figure 1 also shows the potential position of the battery. The battery is considered relatively heavy. Therefore, it might affect the kart balance when choosing the wrong position. It is also essential to consider safety reasons since the battery might explode when damaged. Due to this reason, the proposed position is least exposed to the other elements and ensures the best safety to the battery.

Figure 1. The electric model with the actuator distribution and battery.

Figure 2. The internal combustion engine kart with gasoline tank.

The used electric motors are brushless DC motors. A BLDC motor works similarly to a DC motor according to the Lorentz force law except that in a BLDC motor, the current-carrying conductor is fixed while the permanent magnet is the rotating part. The permanent magnets can vary from two to eight pole pairs with alternate North (N) and South (S) poles based on the required magnetic field density in the rotor, the proper magnetic material is chosen
to make the rotor [1]. In the DC commutator motor, the current polarity is reversed by the commutator and the brushes, but in the brushless DC motor, the polarity reversal is performed by semiconductor switches which are to be switched in synchronization with the rotor position [2]. These motors have a better mechanical structure compared to the conventional DC motors where the permanent magnet rotor provide high efficiency. Due to operating without brushes, the motors will be able to operate at higher load speeds and less friction. In addition to a long working life and lower maintenance requirements.

3. Model structure

Figure 3 shows the top layer of the OMC concept car controller structure.

![Figure 3](image)

**Figure 3.** Controller concept of the OMC car.

The system contains sensors, which are providing data for applications, which are influencing actuators.

**Table 1.** Some features related to the design.

| The sensors used:       | Applications:                        | Actuators:               |
|-------------------------|--------------------------------------|--------------------------|
| - 3D camera             | - Autonomous driving                 | - Linear actuators       |
| - Lidar scanner         | - Vehicle Stability                  | - Servomotors            |
| - Distance sensor       | - Power and Engine Management        | - Brushless motors       |
| - Potentiometer         | - Human Machine Interface            |                          |
| - Encoder (angle sensor)| - Convenient Functions               |                          |
Functions currently under development:

- Microcontroller (Raspberry, Arduino, Mini-pc)
- Throttle sensor
- Gyroscope
- Steering (angle) sensor
- Braking sensor

3.1. ESP

The electronic stability program (ESP) supports the driver in nearly all critical driving situations (Figure 4). It comprises the functions of the antilock braking system (ABS) and the traction control system, but can do considerably more. It detects vehicle skidding movements, and actively counteracts them. The planned structure of this function is shown on Figure 5.

![Figure 4. Basic ESP functions.](image)

3.2. Surrounding environment perception and mapping [4],[5]

INVOLVED SENSORS: The mentioned task is going to be included in the main computer on-board the vehicle (OMK) using the facilities provided by the Robot Operative System core (ROS) and the perception sensors inside the Autonomous Vehicle (AV) as describes on Figure 6.

3.3. Anti-drunk driving car safety system

Description of the Alcohol Detection with Vehicle Controlling system: The main purpose of this project is “Drunk driving detection”. Nowadays, many accidents are happening because of the alcohol consumption of the driver or the person who is driving the vehicle. Thus Drunk driving is a major reason for accidents in almost all countries all over the world. Alcohol Detector in Car project is designed for the safety of the people seating inside the car. Alcohol
Detection with Vehicle Controlling project helps to control the vehicle in case the driver has consumed the alcohol. An alcohol breath analyzer project should be fitted / installed inside the vehicle, implementing GSM technology with an alcohol detector. So Alcohol detection & vehicle controlling through text SMS will inform the relatives or owners of the vehicle about the alcohol consumption. implementing GPS technology so that once alcohol detection is done, the system will find out the location of the vehicle. This project is called GPS tracker and alcohol detector with engine locking system using GSM.

Alcohol Detector project can be used in the various vehicles for detecting whether the driver has consumed alcohol or not. Alcohol Detection System in Cars provides an automatic safety system for cars and other vehicles, as well.

4. **Mathematical modeling**
Mathematical modeling plays an ever increasing role in modern design. It provides a cost effective way to try out different setups and fine tune parameters even before the production of
any kind of prototype. Of course, any mathematical model — let it be a formal or a numerical one — has to be compared to a physical realization eventually. Nevertheless, a well-prepared and efficient model can save time, money and other resources. This whole subsection, including the pictures is based on [3].

For this paper we are going to sketch and discuss a general approach to the aforementioned
Table 2. Components.

| System components: | |
|---------------------|---------------------|
| - Controller board  | - Display           |
| - Alcohol sensor    | - Buzzer            |
| - GSM Shield        | - Relay             |
| - GPS Shield        | - Electric motor    |

ESP control. The idea behind the control system is that nowadays the onboard computers are so small but so powerful that they can be used ubiquitously and for quite serious control purposes. They can provide real time assistance or even direct correction in time of need. Let’s consider the case of the ESP control system using the following familiar model for wheels depicted in Figure 10.

For simplicity we are going to concentrate on the linear case, where the forces acting on the front and rear wheel are the following, respectively:

\[
\begin{align*}
F_y^f &= C_F \alpha_F, \\
F_y^r &= C_R \alpha_R.
\end{align*}
\]

In equations (1) and (2), the linearized side slip angles of the wheels are

\[
\begin{align*}
\alpha_F &= (\delta_F + \Delta \delta_F) - \left( \beta + \frac{\psi v}{v} \right), \\
\alpha_R &= \Delta \delta_R - \left( \beta - \frac{\psi v}{v} \right).
\end{align*}
\]

Here, besides the steering angle \( \delta_F \), we have introduced control through additional steering angles \( \Delta \delta_F \) and \( \Delta \delta_R \). The resulting linear model looks like this, starting with the state and control vectors:

\[
\begin{align*}
x(t) &= \begin{bmatrix} \beta \\ \psi \end{bmatrix}, \\
u(t) &= \begin{bmatrix} \delta_F + \Delta \delta_F \\ \Delta \delta_R \end{bmatrix}.
\end{align*}
\]
The basic linear state equation with initial value has the usual form:

\[ \dot{x}(t) = Ax(t) + Bu(t), \quad x(t_0) = x_0, \]

where the matrices \( A \) and \( B \) are two-by-two and have the following entries:

\[
\begin{align*}
A_{11} &= \frac{C_F + C_R}{mv}, & A_{12} &= -1 - \frac{C_FL_F - C_Rl_R}{mv^2}, & B_{11} &= \frac{C_F}{mv}, & B_{12} &= \frac{C_R}{mv}, \\
A_{21} &= \frac{C_FL_F - C_Rl_R}{I_z}, & A_{22} &= -\frac{C_FL_F^2 + C_Rl_R^2}{I_zv}, & B_{21} &= \frac{C_FL_F}{I_z}, & B_{22} &= \frac{C_Rl_R}{I_z}.
\end{align*}
\]

Here \( m \) is the mass of the car, \( I_z \) is the moment of inertia for the \( z \)-axis and \( C_F, C_R \) are relevant physical parameters of the car. In order to efficiently simulate the system we could use, for example current Multi Body System softwares. To do this we would need to develop an appropriate model. One possible solution is the depicted in Figure 11. For other approaches, see for example [6].

This model combines the input coming from the driver: \( \delta_H \) and \( p_d \), the steering angle and the brake pedal pressure, respectively, with the information gathered by the sensors. The observer provides estimates for \( \beta \), the side slip angle of the vehicle, while the controller computes \( \Delta M_{yaw} \), the necessary yaw moment correction. The job of the transformer is to calculate the necessary correction for the brake pressure. The Actuator closes the loop and steers the vehicle in the corrected direction.

5. Conclusion

The goal of the enterprise is to help students understand better the issues and challenges that they will face as actual engineers, through a highly educational and entirely hands-on projects. They are going to get familiar with every step on the way of building an actual vehicle. This paper is providing information of the project at initiation state. In the future both the demonstration vehicle will be build, as well as the vehicle drive control, vehicle stability control, and convenience functions. From mathematical point of view our current goal is to understand the already existing and accepted model for all parts of the vehicle. In the future we would like to refine the model in such a way that it suits the emerging phisical car better.
Figure 11. An MBS Model for ESP. (Source: [3])

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