BOND GRAPH COMPONENTS FOR MODELLING AN ELECTRICALLY POWERED VEHICLE

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Abstract

The wealth of Bond Graph applications is used in this paper to build a simulation test bed of an electric vehicle. The aim of this work is to interface a dynamic system model with a field network simulator. It is expected to be used as a tutorial and as a support study in current networked control system research. The major constitutive functionalities, of this simplified electric vehicle, are developed to build a complete model. Driving, braking and steering functions are modeled and provided with a set of electric actuators. More precisely five electric actuators compose this modular system. Four of them are located at the rear of the vehicle. Two of which are used for the electromotive power and the two others for the electric braking subsystems. The braking subsystems are modelled as DC actuators based on a ball and screw mechanisms. The electric steering system is located at the front wheel. Its Bond Graph is built around a DC motor and a rack and pinion mechanism. All subsystems make use of a DC motor model, widely covered in the Bond Graph modelling literature. State space models and state feedback control loops are used. The most useful measurements, state variables, control signals and their link with a real time networked system stem from the bond graph junctions. These models are proposed to be used as a support for the implementation of real time scheduling and algorithms of distributed control tasks. Simulation results are presented to evaluate the Bond graph models.

Keywords: Bond Graphs, Electric vehicle modelling , Networked Control Systems.

Presenting Author's biography

Abdennasser FAKRI was born in Casablanca, Morroco, he want to Université de Toulon where he studied Mechanics, next he want to the Unité d'Etude et de Recherche de St Etienne where he studied Physical techniques and electronic instrumentation and obtained his Master degree in 1980. He took his PhD in 1985 from the INSA de Lyon. He worked has Teacher in the Engineers School ENSEM of Casablanca before to join in 1990 the Ecole Supérieure d'Ingénieurs en Electronique et Electrotechnique (ESIEE) where he is now part of the group of Modelling COSI Lab. His email address is: fakria@esiee.fr and his web page can be found at http://www.esiee.fr/~fakria.

1 Introduction

In a recent paper, we proposed models of elements composing an electric driven vehicle [1]. The subsystems of this vehicle should be controlled through a field network medium. The intent is to have a test bed to study the main features of this vehicle in terms of distributed measure and control. The fact is that recent vehicles and especially those using hybrid energy or exclusively electric energy, use an increasing number of active electronic devices. Nowadays, it is admitted that the reliable and correct functioning of these vehicles requires a large number of sensors, actuators and data processing devices. This need of instrumentation favored a wide development of distributed control through field network. Specifically, the CAN network (Control area Network, by Robert Bosh GmbH) is largely used to make communication links between electronic elements. These control networks allow to collect, multiplex, carry and distribute signal measurements as well as input references of closed loop controls. Since many years, the setting up of these field networks, aims to reduce point to point communication and improve the links between the subsystems. The networked control technology transforms a hardware complexity into a software one due to the control distribution through the network medium. Many developments in scheduling of networked control systems, largely contribute to control system research [2] and their implementation in distributed and real time constrained systems. Optimised methods and control algorithms become essential to schedule the network functionality [3].

For the reliability of current vehicle, real time data processing is vital. Hence theoretical developments, performances and validations of the control algorithms require the availability of a simulation test bed. Using Bond graph methodology[4][5][6], this paper details modeling of such a test bed. Some graphical tools dedicated to Bond Graph approach [7][8] facilitate complex physical systems representation and simulation. In the sections that follow several aspects of the test bed structure are presented. In section 2 the guiding scheme of the test bed is presented. We further introduce a kinematics' equations to study the models' behavior. Section 3 is devoted to the bond graph model of a DC motor used as a basis actuator. Section 4, 5 and 6 present respectively driving, braking and steering subsystem models. Conclusions and future work are given in the last Section.

2 The electric test bed

The composition of the test bed studied is an assembly of mechatronic modules. Before to develop the bond graph models, let us present in figure 1 the guiding scheme of this platform. The left and right back drive wheels are endowed with DC motor drives (MDL, MDR) and with motorized braking systems (BSL, BSR).

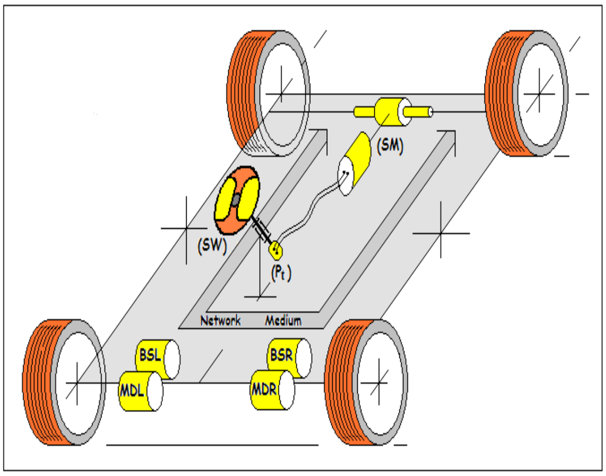
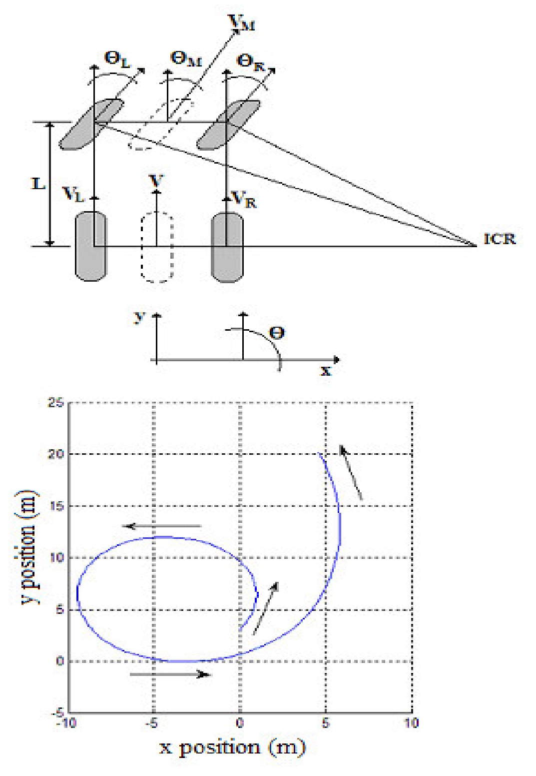


Fig. 1 Guiding scheme of the electric vehicle



$$\dot{x} = V_M \cos\Theta_M \cos\Theta$$

$$\dot{y} = V_M \cos\Theta_M \sin\Theta$$

$$\dot{\Theta} = \frac{V_M}{L}\sin\Theta_M$$

$$\Theta_M = arctg\left(\frac{2\,tg\Theta_L \cdot tg\Theta_R}{tg\Theta_L + tg\Theta_R}\right)$$

Fig. 2 Two wheels model for car steering

Front wheels are equipped with an electric steering system (SM) powered by a DC motor. A potentiometer (PT) linked to the steering wheel (SW) drive the rotation system. The aim of the modeling is to isolate active variables, commonly sources or junctions and state variables of the models. Some of those state variables can serve for the distributed regulation loops, and can be connected to the field networks. A practical and easy way to build the model of this modular test bed is the use of the bond graph metrology. This graphical modeling tool has a particular capacity to represent complex and mixed physical domain like mechatronic systems [9]. The active electric functions of the vehicle are essentially built around a basis component, represented by a Dc motor. Before presenting the vehicle subsystems we use an Ackerman-Janteau model for car steering to highlight the useful kinematic variables for our study. Features of vehicle steering kinematics in a horizontal plane is shown in Figure 2. The angle $\boldsymbol{\theta_M}$ is the front steering angle, $\mathbf{V_M}$ is the longitudinal velocity of the midpoint of the front wheel axle, $\boldsymbol{\theta}$ is the orientation angle and **L** is the wheel base. The vehicle location is referenced by the coordinate variables **x**, **y** and $\boldsymbol{\theta}$. Including those variables or there derivatives $(\dot{x}, \dot{y}, \dot{\Theta})$, the vehicle equations of motion and the calculus of the steering angle $\boldsymbol{\theta_M}$ are given in Figure 2. Assuming that $\mathbf{V=V_L=V_R}$ we can use the two wheels equivalent model represented by dotted lines.

The variable $\boldsymbol{\theta_L}$, $\boldsymbol{\theta_R}$, $\mathbf{V_L}$ and $\mathbf{V_R}$ required for the simulation of the of the motion are produced by the bond graph models presented below.

3 The basis actuator

The Bond Graph model of this actuator is presented in Figure 3. This model of DC motor is classic and is widely used as tutorial example in the Bond graph literature.

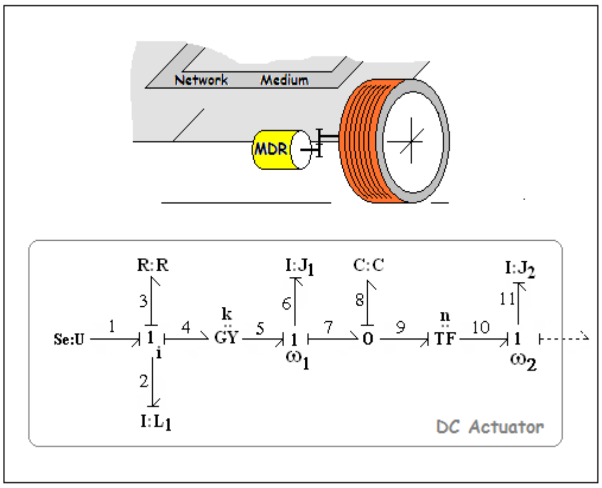


Fig. 3 Model Bond Graph of the main actuator (DC motor)

Detailing this model, let us underline the roles of the gyrator GY that connects the electric and mechanical energies and of the transformer TF that acts as velocity reducer. R and L_1 are the DC motor parameters. J_1 and J_2 represent the Motor shaft and the wheels inertias. Element C acts as the transmission stiffness drive.

Three state variables are useful for the study: the motor's current I, The velocity w1 of the motor's shaft and the velocity w2 transmitted to the vehicle wheel. These variables are useful for the automatic observation and control. They could be be connected to the field network. The state equations of the DC model bond graph are proposed in Figure 4. The simulations focus on the velocity $\boldsymbol{\omega_2}$ considering open and closed loop control results. This variable is the most interesting for the rest of this modeling work. The state feedback control for this model uses a classic pole placement method. Let us highlight that this actuator represents the main component of the subsystem models we develop in the following.

$$[\dot{X}] = \begin{bmatrix} \dot{p}_2 \\ \dot{p}_6 \\ \dot{p}_{11} \\ \dot{q}_8 \end{bmatrix} = \begin{bmatrix} -\frac{R}{L_1} & -\frac{k}{J_1} & 0 & 0 \\ \frac{k}{L} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{n\times C} \\ 0 & \frac{1}{J_1} & \frac{1}{n\times J_2} & 0 \end{bmatrix} \times \begin{bmatrix} p_2 \\ p_6 \\ p_{11} \\ q_8 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$Y = \begin{bmatrix} i \\ \omega_1 \\ \omega_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{L_1} & 0 & 0 & 0 \\ 0 & \frac{1}{J_1} & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{J_2} \end{bmatrix} \times \begin{bmatrix} p_2 \\ p_6 \\ p_{11} \\ q_8 \end{bmatrix}$$

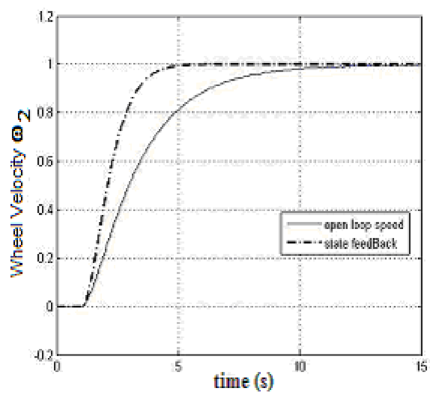


Fig. 4 State Space model and simulation results (velocity w2)

4 Driving subsystem

Opposite to the model previously proposed in [1], driving wheels are located at the rear axle of the vehicle. That gives the possibility to use the test bed to study a steeringless motorized wheelchair model. Figure 5 shows scheme and model of the the two drive actuators coupled to the rear axle. The Bond graph model of this subsystem uses, as input sources, two embedded actuators, whose velocities are state feedback controlled (see Figure 3). The graphic model is built around the state variables $V_L, V_R, \dot{\Theta}_g$ and V_g. These kinematic variables are also eligible for measurement and control through a field network. The dynamic model of the mechanical architecture is not linear because the presence of the modulated transformers (MTF).

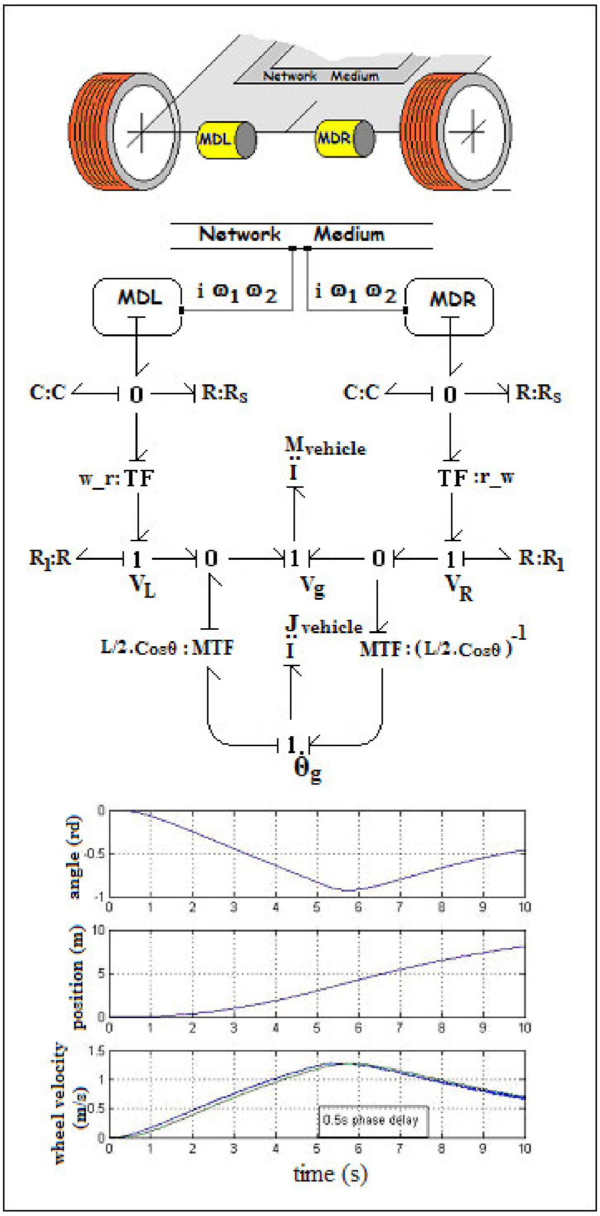


Fig. 5 Model of the driving subsystem

5 Braking subsystem

The braking subsystem is likewise localized at the rear of the. It consists of two devices placed on the left and the right wheels. The simplified principle scheme was developed in [1]. One can find a bond graph model such a system in [11]. The functioning of the electric braking model is based on a ball screw mechanism. The distance d between the brake-pad and the brake-disc is the initial value of x, that represents the position of the brake-pad. The relation between the braking force N and the variable x is modelled by a dead zone function N(x) as shown in Figure 6. The Bond graph model of this braking force is represented by a modulated resistance function R(N). The ball screw system is modeled by a Bond graph two ports Gyrator GY:g.

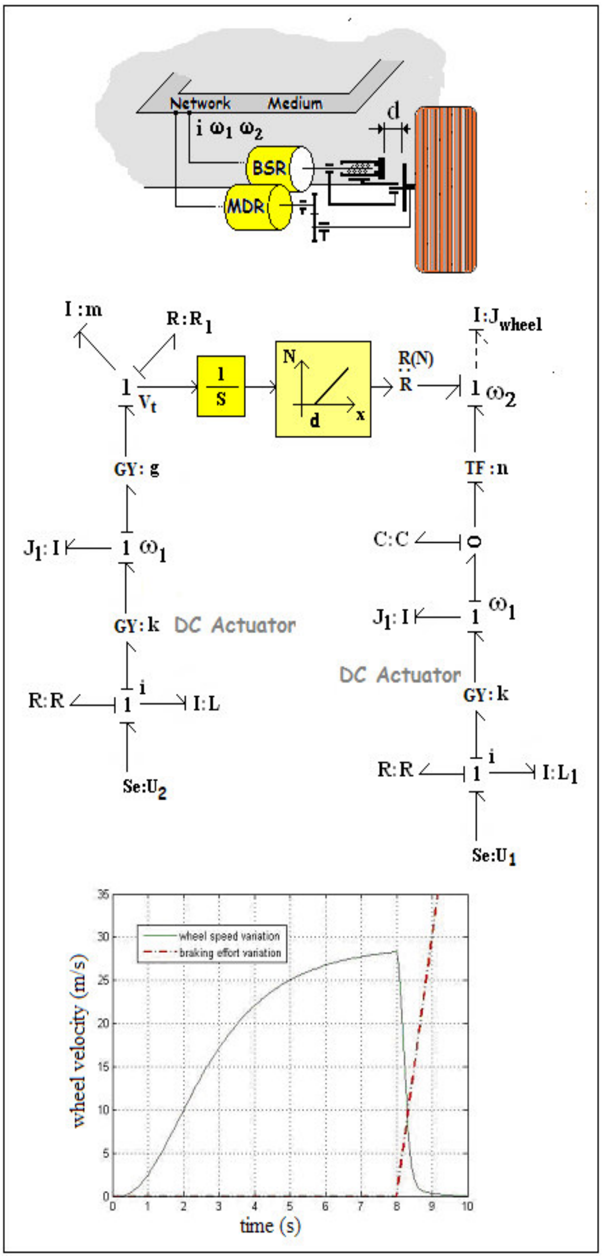


Fig. 7 : Model of the electric steering device

The braking effort increases when the distance **d** is covered, thus the brake-pad reaches and pushes against the brake-disc. Figure 6 shows both the driving and braking mechanisms of the right wheel. As mentioned, the braking system also uses the elements of a basis actuator. The proposed simulation result shows the effect of the braking torque increasing in relation to the wheel velocity, that decrease rapidly.

6 Steering subsystem

The scheme of the steering subsystem and its Bond graph model are presented in Figure 7 below.

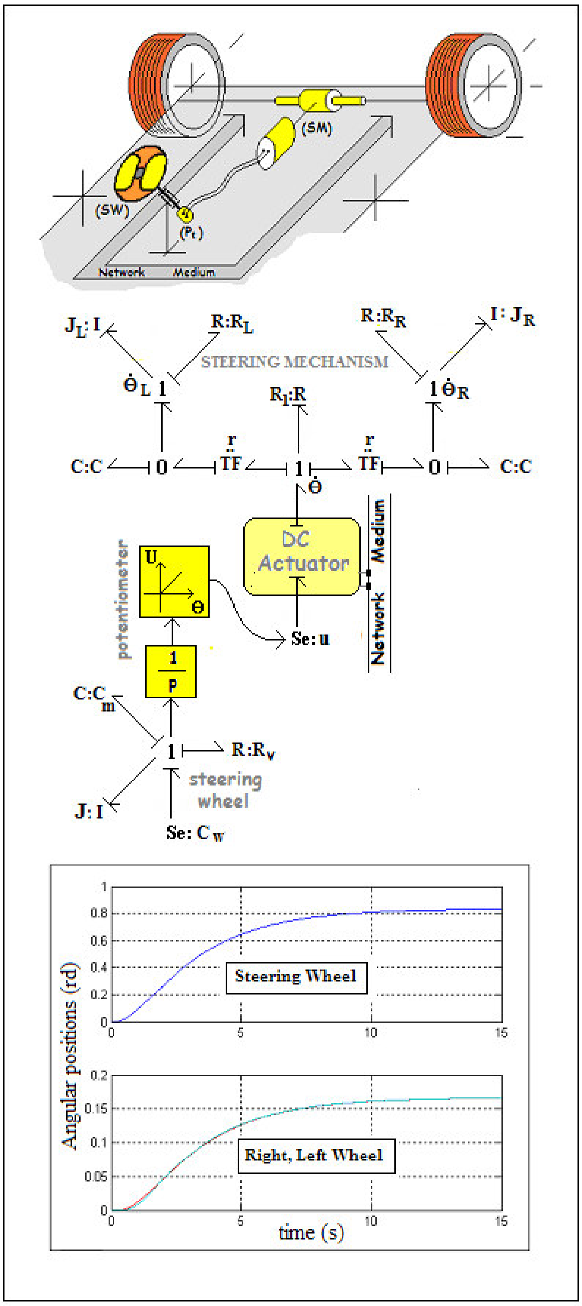


Fig. 7 : Models of the electric steering device

below. The steering command is transmitted by the steering wheel to the DC motor through a potentiometer (Pt). The tension value given to the actuator is proportional to the angle of the potentiometer. A rack and pinion system transforms the actuator rotation velocity to wheel velocity rotations $\dot{\Theta}_L$ and $\dot{\Theta}_R$. These variables are extracted from the flux junctions of the Bond graph model and their integral functions Θ_L and Θ_R are supplied to the kinematic model presented in section 2. The Simulations, Figure 7 show the angular variations of both the steering wheel and the front wheels of the test bed. From this subsystem also, numerous junction variables would be connected to the network medium model.

7 Conclusions and future work

Models of subsystem constituents of a simplified battery-driven vehicle are proposed in this paper. The models developed, based on a recent previous work, are improved [1]. They can be used as a tutorial to Bond graph study and as a support for current networked control systems development. This increasingly used graphic methodology allows a modular approach for the design of an electric vehicle model. Every feature can be separately studied, simplified and improved. Components of this test bed present a set of dynamic variables stemmed from Bond graph junctions, flux or effort sources elements. These variables are particularly useful and facilitate interfacing with the field network model. Thus, the vehicle plan can be considered as a support study for the design and the analysis of the network scheduling strategies and protocols. Future work will concern modelling and simulation of real time closed loop control of the actuators distributed through field network model.

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