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MOTION SIMULATION OF A PATH CONTROLLED VEHICLE

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The dynamical modelling of a path controlled vehicle is analyzed in this paper. In addition to the discussion to determine the orientation and location of a vehicle the problems of redesigning a commercial mini car are also discussed. Special emphasize has been laid on the dynamical analysis of the model in the starting transient period. A simple controlling were also attached to the model The velocity, current flow and the roamed path have been obtained.

Keywords: Path Control, Motion Simulation, Dynamical Analysis, Dynamical Model

Introduction

The number of application of automated guided vehicles is increased in logistics during the last decades [1]. By the use of such vehicles, one can decrease the expenditure of the production cost and increase the operational efficiency and its reliability.

In this paper the designing aspects of a path controlled vehicle is discussed. It is essential to solve the navigational problem, i.e., the vehicle should be moved from the initial position to the final one through a predefined path. The path can be defined by fixed methods e.g., painted paths, inductive loops, and by flexible methods, i.e., mathematical definition of the path which can be combined by GPS or other navigation systems.

In this paper the later approach will be preferred, since the modification of a path can be carried out easily by changing the mathematical definition in the software. The advantage of this method is the arbitrary path definition, but its disadvantage is lower accuracy. The accuracy can be improved by feedbacks. In addition to logistics wide range of applications of such vehicles can be found e.g., scanning on a minefield or mowing the lawn automatically.

The design and dynamical modelling of a path controlled vehicle are detailed, its accuracy is less than 0.1 m. The first part of the paper deals with the problem of the sensing and correction of the vehicle position. In the second part the vehicle will be redesigned to follow paths. In the third part the electro-dynamical model of the vehicle is analyzed.

Methods determining orientations and locations

According to the introduction, guiding on a flexible path requires a position and orientation sensing methods, whereby the moving of the vehicle is controlled. These methods are based on different types of sensors, which provide feedbacks for the calculations.

The orientation and position sensing methods can be divided into three groups [4, 5]: odometrical method is based on step counting and is carried out by summarizing the relative motion information, absolute method is based on distance measuring from objects at known positions and other methods.

The odometrical distance measuring gives indirect information about the movement, which can be:

- Angular position sensing with rotary encoder by an absolute or an incremental one depending on the specific construction. The two methods can be distinguished by the applied rotating disc and the assigned signal processing. These encoders are mounted on the shaft.
- Measuring the revolution of the motor in the drive train with optical, inductive, capacitive or hall sensor, e.g., teeth of a metal gear passing by an inductive sensor, or sensing the symmetrically placed magnets on the side of a gear with hall sensors.
- Motor independent movement sensing system with a measuring wheel or a measuring ball, e.g., mechanical computer mouse.

The odometrical distance measuring methods may have regular and irregular errors. The measuring error is incremental so the calculated position should be refined regularly by absolute distance measuring methods. During absolute distance measuring the position is calculated by known position objects which are called marker points. These points can be active or passive, and natural or artificial depending on the construction. Absolute distance measuring methods:

- Optical marker technique. Setting or using visually distinguishable points in the area.
- Laser and ultrasonic technique. Instruments based on triangulation method are using the beam to set the direction. Instruments based on phase modulation or radar principle the beam as an electro-magnetic wave to determine the distance between the measuring equipment and the signal point can be used.
- Radio principle positioning system. The positioning requires to set up a radio based local positioning system or an existing system, e.g., GPS can be utilized for it.

Comparing the odometrical distance measuring with the absolute distance measuring one can state that the later has only a regular error which is constant. The absolute technique is a time consuming method, therefore it is used rarely. It means that the less expensive odometrical position determination can be refined by an expensive one.

There are also other location and orientation determining methods, e.g., Doppler sensor or a system provided by accelerometers, gyroscopes or their combinations.

Redesigning of a commercial car for path controlling

In order to study path controlling, a commercial Tyco rebound radio controlled mini car has been redesigned. The redesigned vehicle contains the following functional parts:

- The controller electronics is a dsPICDEM MC1 Motor Control Development Board, which contains a dsPIC30F6010a microcontroller. The software is written in C programming language.
- The sensors (TLE4905L) are creating digital TTL voltage level signal for the controller electronics, when one of the 4 neodymium magnets on the side of the gear is passing by.
- The power PCB (Printed Circuit Board) is containing the socket for the motor, optical coupling to the controller board and the power supply of the Hall sensors. The power PCB physically contains an integrated Full H-bridge (L298N), +5 V supply for the TTL logic (KA7805) and the optical coupler integrated circuit (CNY74-2H).

The position is determined by the wheel revolutions on different sides (by odometrical method), the principle is shown in *Fig. 1*. It is clearly visible, how the vehicle is moving along the arc $\Delta\alpha$ if only one of the sides is driven with one increment.

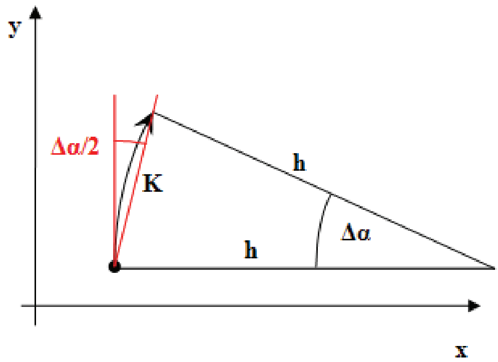

Figure 1: Calculation of the rotation belonging to one increment

From geometrical considerations, the coordinates of the vehicle could be calculated increment by increment:

$$x_{n+1} \cong x_n + K \sin\left(\alpha_n + \Delta\alpha / 2\right), \qquad (1)$$

$$y_{n+1} \cong y_n + K \cos\left(\alpha_n + \Delta\alpha / 2\right), \qquad (2)$$

where $\Delta\alpha = \pm K / h$ depends on the directions, i.e., in case of +/- the movement is forward/backward, the value of K is the arc length associated with one increment and h is the radius of the path. During the calculations of the coordinates the angle should be increased by π.

Learning mode of the vehicle operation has been developed, while data of the whole path are saved by the software. Afterwards the path data is accessible on a personal computer via RS-232 communication.

Furthermore a preprogrammed mode is accessible, when the vehicle is controlled by itself performing a preprogrammed path. The motors are controlled via the power PCB by PWM (Pulse Width Modulation) signals.

During the test of the redesigned vehicle two important vehicle attributes have been determined for the software: $h = 3.625$ m and $K = 42.25$ mm.

Dynamical analysis of the vehicle

The wheels on the two sides of the vehicle are controlled independently by two DC motors. The characteristics of the LRE260-18130A type DC motor are given as: operating range 1.5–4.5 V, nominal 3 V, (at no load: speed 6900 r/min, current 0.095 A), (at maximum efficiency: revoultion 5000 r/min, current 0.37 A, torque 9.5 gcm), (at stall: torque 48 gcm, current 1.4 A). The gear transmission between the wheels and the motor is $i_{m,w} = 1{:}28.3451$.

The dynamical model of the vehicle [6] can be formulated by measuring the electrical and dynamical parameters, and using the catalogue values of the motors. During the straightforward motion of the vehicle, the complex mechanism can be modelled by a one degree of freedom system, where the general coordinate is the angular rotation of the motor shaft ($q = \varphi$).

The electro-dynamical equations are written as:

$$J \frac{d\omega}{dt} + b\,\omega = 2 \cdot k_t\, i - M_t, \qquad (3)$$

$$L\frac{di}{dt}+R\,i+k_e\,\omega=V-2V_B\,, \qquad (4)$$

where J is the reduced inertia moment, $\omega = \dot{\varphi}$ is the angular velocity of the motor shaft, b is the damping coefficient, $2{\cdot}k_t$ is the motor constant for two motors, M_t is the reduced loading torque, i is the current, V is the applied armature voltage, L is the armature inductance, R is the armature resistance and k_e back EMF constant ($k_t \cong k_e$).

The reduced inertia moment J is derived by the inertia moments with respect to point A of the four wheels $4{\cdot}J_k$ (see *Fig. 2*), and the inertia moment due to the rest of the vehicle mass m_v. The inertia moment of a wheel is determined by the period T of a pendulum and using the formula $J_k=\frac{m_k\,g\,r}{4\pi^2}T^2$.

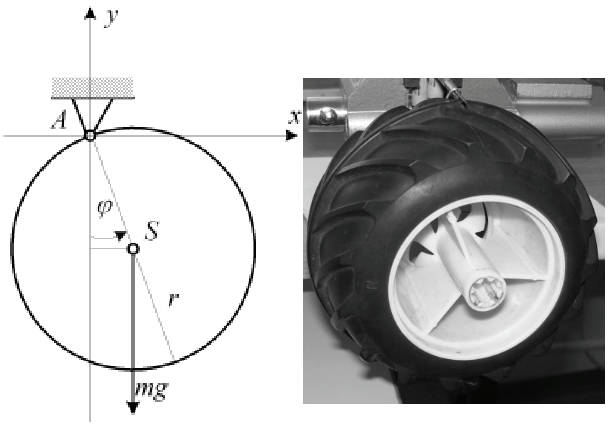

Figure 2: The wheel as a pendulum

The mechanical parameters of the model are given as: $m_v = 0.686$ kg, $m_k = 0.091$ kg, $T = 0.59$ s, $r = 0.051$ m, $J = 1.731{\cdot}10^{-5}$ kgm^2. The loading torque is changing in relation of the angular acceleration, until a certain value. The inductance of the armature is $L = 3.28{\cdot}10^{-4}$ H. At the three working conditions stall, maximum efficiency and idle. One can obtain the brush voltages $2V_{BS} = 0$ V, $2V_{BM} = 0.446$ V and $2V_{BN} = 0.5493$ V, respectively. The brush voltage loss is approximated by a quadratic function $2V_B = A\omega^2 + B\omega$, where $A = -4.615{\cdot}10^{-7}$ Vs^2 and $B = 1.094{\cdot}10^{-3}$ Vs (see *Fig. 3*).

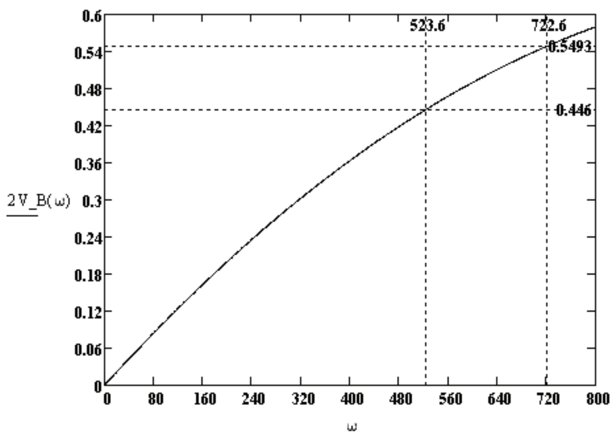

Figure 3: Approximation of the brush voltage loss

The systems of equations (3, 4) have been solved for homogenous initial conditions by Matlab Simulink program system. The controlling software is developed in C language, to shorten the calculation time. The simulated path during the path controlling is shown in the *Fig. 4*. Three points are programmed to reach, which are A tolerance is used for passing the points. After reaching the last programmed point [500;1000], the control switches to zero, when the motors are working as generators until the vehicle stops.

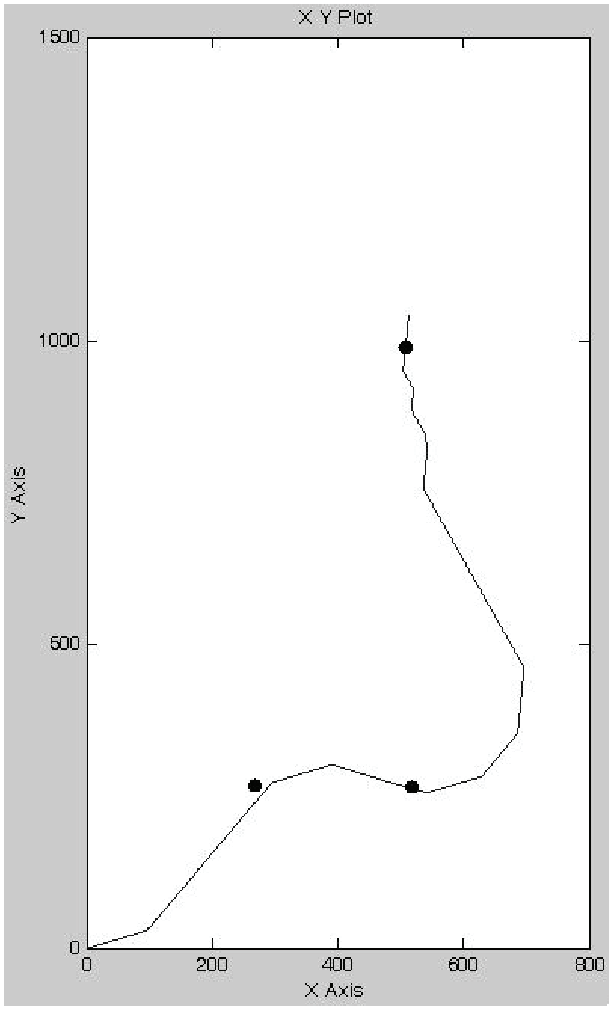

Figure 4: The roamed path

Two of the four output parameters, i.e., currents, angular velocity, angular acceleration, velocity of the vehicle, are shown as a function of time in *Fig. 5* and *6.* In Fig. 6 the lighter line represents the current for the right motor, and the darker for the left one. Due to the loading torque, the vehicle reaches the maximum value of velocity after ~10 seconds. When the control is turned off, the vehicle slows until the back emf value reaches zero. One can see how the control is changing rapidly, when the vehicle is moving on a “zig-zag” path. In this case the control changes in almost every calculation cycle, hence the motors are alternating between motor and generator state.

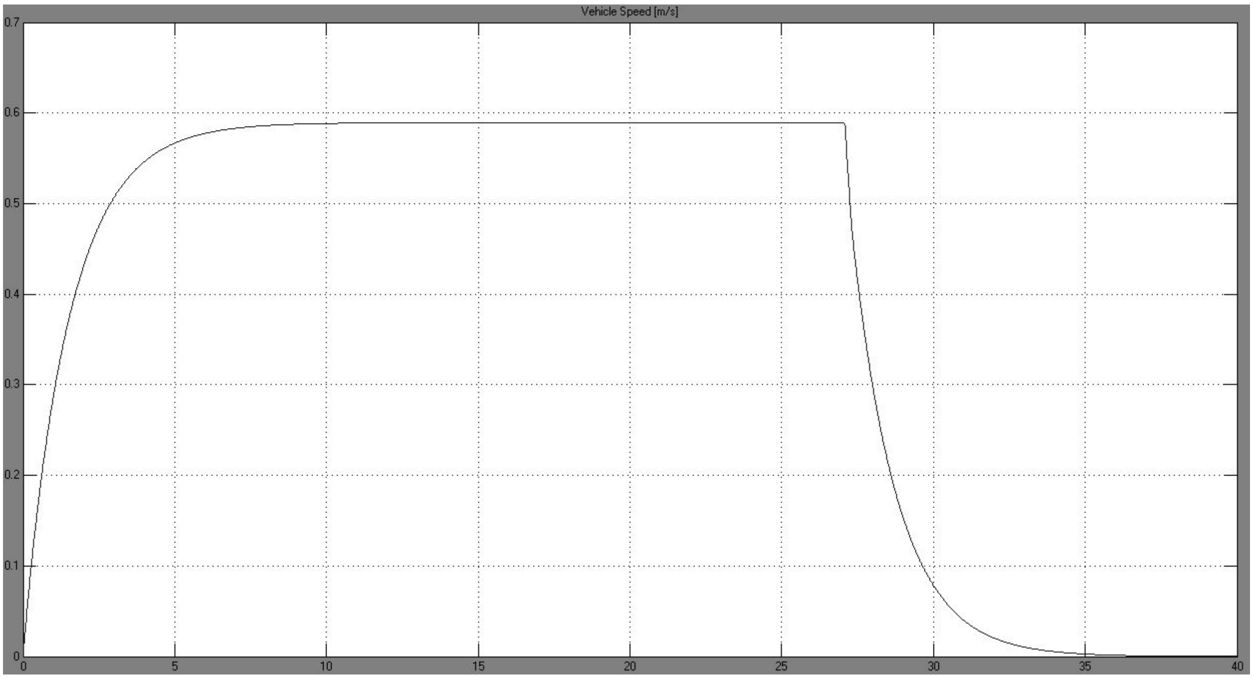

Figure 5: The velocity of the vehicle during the controlling

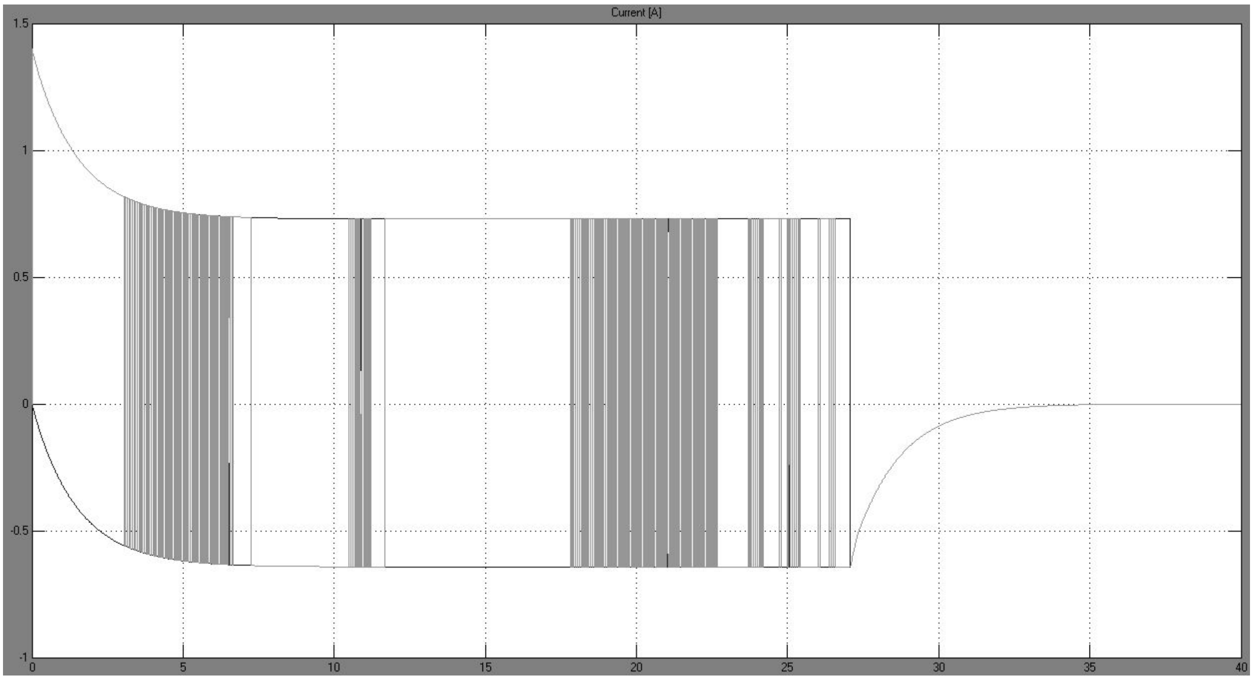

*Figure 6:*The currents of the motors

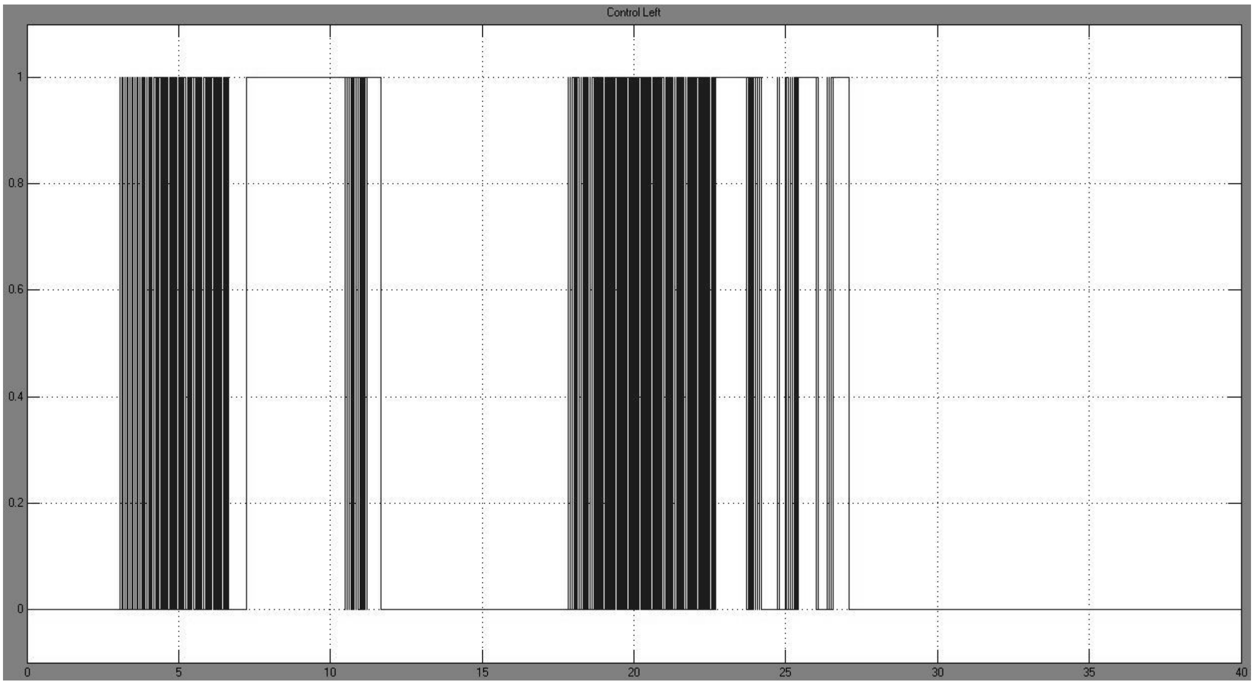

Figure 7: The digital control signals of the left motor

In *Fig. 7* one can see, how the control is changing throughout the simulation for the left motor. Before reaching the last point, the motors are fed alternatively, so the control for the right motor is the opposite of the left one.

Summary

The dynamical modelling of a path controlled vehicle is analyzed in this paper. In addition to the discussion to determine the orientation and location of a vehicle the problems of redesigning a commercial mini car are also discussed. Special emphasize has been laid on the dynamical analysis of the model in the starting transient period. A simple controlling were also attached to the model The velocity, current flow and the roamed path have been obtained.

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