Wheelchair Control and Navigation Based on Kinematic Model and Iris Movement

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***Abstract* — This paper deals control and navigation of the wheelchair for elderly and disabled based on kinematic model iris motion and image processing. Cirrus Power Wheelchair was modelled as an wheeled mobile robot (WMR) with two driving and two free wheels (2DW/2FW). An input/output model of the wheel control system consisting of servo-amplifier, DC motor and gear reducer have been experimentally indentified. To control each driving wheel system, PI controller has been used. Pole placement method was used for tuning PI controller. A software solution was proposed for real-time computing of the wheelchair position based on data acquisition from whell encoders. A navigation system, based on iris movement and image processing, was real-time implemented in MATLAB. This navigation system identifies the user's eye movement in three directions: forward, left and right. Stop of the wheelchair is done by eye closing. Using a LabView platform, a graphic user interface has been designed and implemented, allowing user to control wheelchair movements.**

Keywords—wheelchair; control; navigation; kinematic model; iris movement.

I. Introduction

The progress in mobility of the wheeled mobile robots (WMR) made possible its application in various and useful fields, like the use of intelligent powered wheelchairs to assist handicapped and elderly people. Most of the research work on robotic wheelchairs (and differential drive vehicles in general), incorporate classic solutions for low level control and concentrate design efforts on high level control (path following and trajectory tracking). The literature addressing the problem of motion under nonholonomic constraints using the kinematic model of a mobile robot is vast. On the other hand, little has been written about the integration problem of the nonholonomic kinematics controller and the dynamics of the mobile robot. Furthermore, there is a small amount of works on robustness and control in presence of uncertainties in the dynamical model of such systems. Several results on the control of nonholonomic systems with uncertainties have been obtained. These results concern the back-stepping technique applying to the adaptive control of nonholonomic systems with unknown parameters. This paper proposes a path following controller based on WMR's kinematic model and acquisition data from encoders that is robust against localization errors. This controller is a path-following sliding-mode controller, for a car-like robot, claiming robustness to localization and curvature estimation errors. Also, this paper proposed a navigation system based on iris and eye movements, allowing obstacle avoidance.

The rest of the paper is organised as follows: in Section II, nonholonomic wheelchair kinematic model is laid out; driving wheel control system is presented in Section III; Identification of driving wheel DC motor model is shown in Section IV; tuning PI controller parameters is done in Section V; a solution for data acquisition from encoders, is elaborated in Section VI; wheelchair navigation based on iris movement and image processing together a graphic user interface designed in LabView are presented in Section VII,; some final remarks can be found in Section VIII.

II. Nonholonomic Wheelchair Kinematic Model

Fig 1 shows a geometric model of a wheelchair that defines the main variables necessary to obtain kinematic model [1].

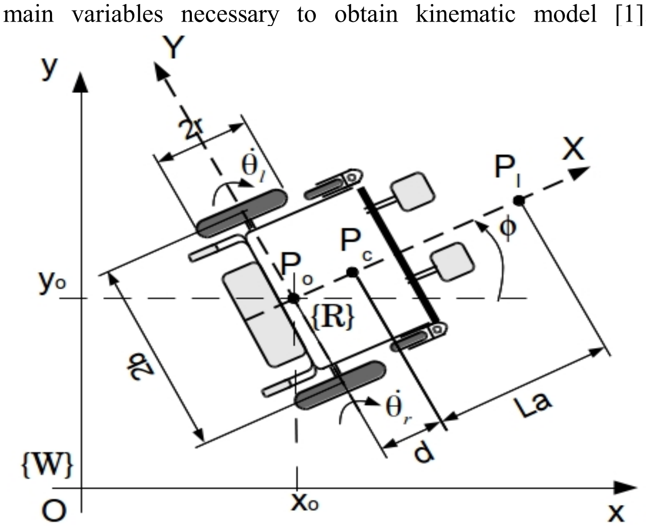

Fig. 1. Wheelchair modelled as wheeled mobile robot with two driving wheels and two free wheels (2DW/2FW)

This WMR has two diametrically opposed drive wheels (radius r) and free-wheeling castors. Both drive wheels are actuate and sensed, while the castors are neither actuated nor sensed. Thus, the castor wheels are not considered in getting of kinematic and dynamic models. P_0 defines the origin of the robot coordinate system with coordinates (x_o, y_o). P_c is the center of mass of the robot with coordinates (x_c, y_c) and is placed in the X-axis at a distance d of P_o. P_l is a virtual reference point attached to the platform with coordinates (x_l, y_l) and is placed in the X-axis at a distance L_a of P_c. $2b$ is the length of the axis between the wheels of the mobile robot. ϕ is the angle between x-axis of $\{W\}$ and the X-axis of $\{R\}$. $\dot{\theta}_r$ and $\dot{\theta}_l$ are the angular velocities of the right and left wheels around the Y-axis.

The equilibrium of the wheelchair is maintained by two front free wheels and other two rear small wheels, whose effect it will ignore. Thus,

$$q = [x_c, y_c, \phi, \theta_r, \theta_l] \tag{1}$$

denotes the configuration of the system, i.e. the five generalized coordinates $(n = 5)$. In the kinematic model it is suppose that in each contact exist a pure rolling motion. Assuming that the velocity of P_o must be in the direction of the symmetry (X-axis) and the wheels do not slip, the following constraints set $(m = 3)$, with respect to P_c, is obtained [8]:

$$\dot{y}_c \cos\phi - \dot{x}_c \sin\phi - \dot{\phi} d = 0 \tag{2}$$

$$\dot{x}_c \cos\phi + \dot{y}_c \sin\phi + b\dot{\phi} - r\dot{\theta}_r = 0 \tag{3}$$

$$\dot{x}_c \cos\phi + \dot{y}_c \sin\phi - b\dot{\phi} - r\dot{\theta}_l = 0 \tag{4}$$

These constraints can be rewritten in the matrix form:

$$A(q)\dot{q} = 0 \tag{5}$$

with

$$A(q) = \begin{bmatrix} -\sin\phi & \cos\phi & -d & 0 & 0 \\ -\cos\phi & -\sin\phi & -b & r & 0 \\ -\cos\phi & -\sin\phi & b & 0 & r \end{bmatrix} \tag{6}$$

Considering the mobile robot kinematics $S(q)$ is defined by:

$$S(q) = \begin{bmatrix} c(b\cos\phi - d\sin\phi) & c(b\cos\phi + d\sin\phi) \\ c(b\sin\phi + d\cos\phi) & c(b\sin\phi - d\cos\phi) \\ c & -c \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \tag{7}$$

that satisfies the equation

$$A(q)S(q) = 0 \tag{8}$$

where the constant $c = r/(2b)$. The kinematic model, is given by

$$\dot{q} = S(q)v(t) \tag{9}$$

with

$$v = [v_R \quad v_L]^T, \; \nu = [\dot{\theta}_R \quad \dot{\theta}_L]^T \tag{10}$$

Concerning the robotic system in study, Δ distribution is involutive and the system is controllable.

III. Driving Wheel DC Motor Modelling

To control a DC motor must have the mathematical model of the motor [2]. The mathematical model must be able to determine a relationship between the angular velocity of the rotor and its applied voltage.

To get the input/output model of wheel DC motor, having as input the armature voltage and as output angular speed, we can write the steady-state mechanical and electrical variables:
(1)

$$\omega(t) = \frac{d\theta}{dt} \tag{11}$$

$$e_b(t) = K_b \frac{d\theta}{dt} \tag{12}$$

$$e_a(t) = R_a i_a(t) + L_a \frac{di_a}{dt} + e_b(t) \tag{13}$$

(2)

$$T_m(t) = K_t i_a(t) \tag{14}$$

$$T_m(t) = J\frac{d\omega}{dt} \tag{15}$$

where: R_a is armature resistance, L_a is inductance armature T_m is active torque, i_a is current through the armature circuit; e_a is input electromotive voltage, e_b is counter electromotive voltage, ω is angular speed, J is moment of inertia of the motor shaft and K_b, K_t are motor constants.

Setting $U_a(s) = E_a(s)$ as control input, then it can express, in Laplace, the transfer from the control input to the angular speed output as follow

$$\Omega(s) = H(s)U_a(s) \tag{16}$$

After some calculus manipulations, the transfer function (16) becomes

$$H(s) = \frac{K_m}{\frac{JT_a}{K_a K_t K_b}s^2 + \frac{J}{K_a K_t K_b}s + 1} \tag{17}$$

where: $K_m = 1/K_b$, $T_a = L_a/R_a$, $K_a = 1/R_a$.

Because the s^2 coefficient is small (T_a is small) compared to the coefficient of s, then we can neglect the term containing s^2. Therefore, the transfer function (17) becomes in approximate form

$$H(s) = \frac{K_m}{\tau s + 1} \tag{18}$$

where: $\tau = J/(K_a K_t K_b)$.

To control DC motors we need mathematical model of the whole driving wheel system consisting of servo amplifier, DC motor and speed reducer [3].

For controlling brush DC motors were used servo amplifier 50A8, shown in Fig.2. It can receive data from acquisition board and, based on the received signal, the servo-amplifier will send a PWM control signal to DC motor, signal having a duty cycle dynamically modifiable. For data acquisition and control signal sending to the DC motors has been a NI-6024 acquisition card, also shown in Fig. 2. It has 16 analogue inputs, two analogue outputs 8 digital inputs and 8 digital outputs.

The communication between the motherboard and data acquisition card is a PCI slot. This device connects to PC the servo-amplifies, DC motors and the encoders (Fig. 2). PC processes signals and data necessary for odometer system implementation. Cirrus Power Wheelchair fully equipped with PC, data acquisition card, servo-amplifiers, DC motors, encoders and batteries is shown in Fig. 3.

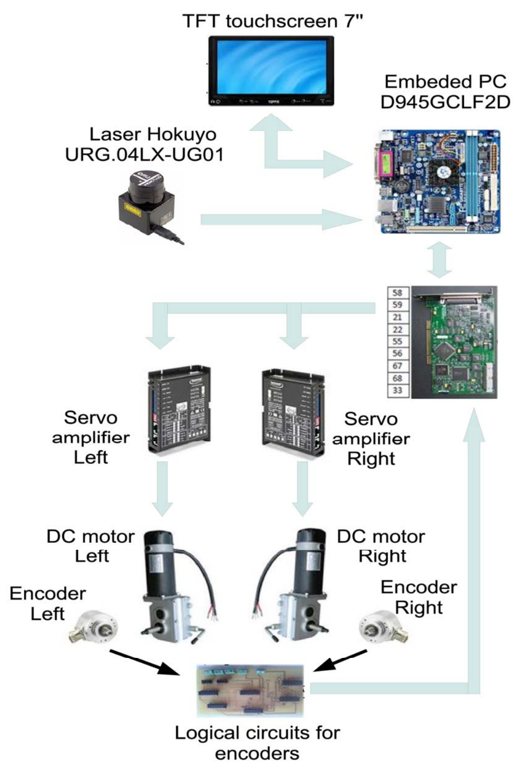

Fig. 2. Control and navigation hardware

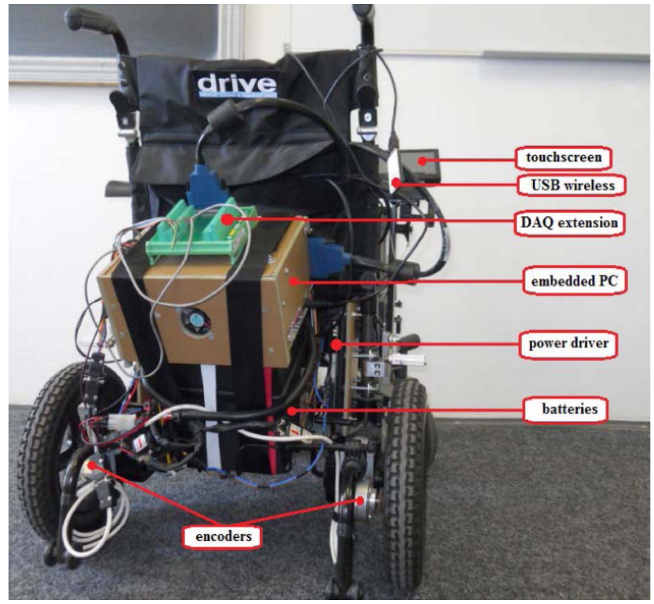

Fig. 3. Equipped Cirrus Power Wheelchair

IV. Driving Wheel DC Motor Model Identification

To identify the transfer functions of the two wheel control systems MATLAB's SYSTEM IDENTIFICATION toolbox, [4]. This toolbox allows identifying parameters of transfer function (18) the mathematical model of systems from input/output acquisition data from each driving wheel control system.

To obtain the parameters of transfer function for each diving wheel control system (servo amplifier, DC motor, angular speed reducer) we have to acquire output data (angular speed) applying a voltage signal to the input.

The data acquired from the two sensors that measuring the angular speed of the two drive wheels are showin Fig. 3 and Fig 4.

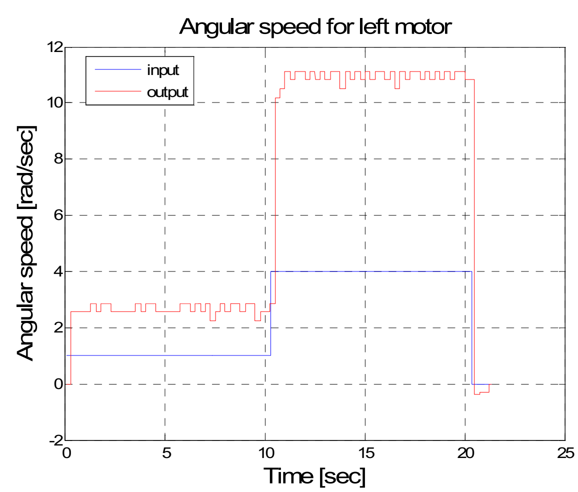

Fig. 4. Left DC motor angular speed to an input variable step voltage (voltage applied to servo amplifier)

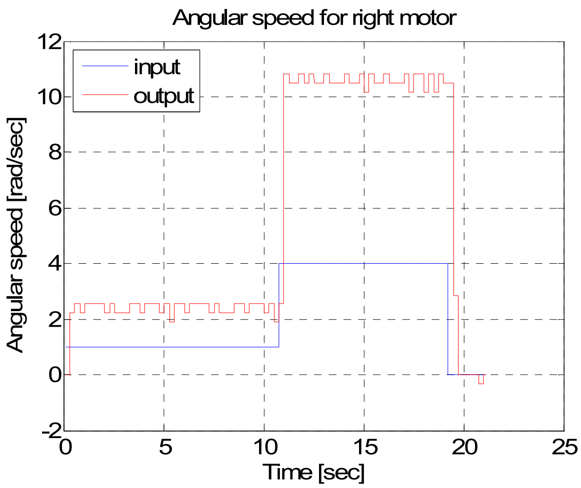

Fig. 5. Right DC motor angular speed to a variable step voltage input(voltage applied to servo amplifier)

Due to parameter identification, were obtained the following transfer functions corresponding to each wheel (left and right) control sytem

$$H_L = \frac{2.6}{0.28s+1} \tag{19}$$

$$H_R = \frac{2.7}{0.3s+1} \tag{20}$$

V. Tuning PI Controller Parameters

Since the transfer functions of the control systems for both drive wheels, are first-order, then it will use a PI controller. By using pole placement method, ([3], [4], [7]) allows to compute parameters of both PI controllers, K_P and K_i.

Pole placement method revealed the following values:

$$K_{P_L} = 0.6\,,\; K_{i_L} = 2\,,\; K_{P_R} = 0.5\,,\; K_{i_R} = 2.1 \tag{21}$$

The experimental results using PI controllers embedded in WINDOWS REAL-TIME TARGET in MATLAB are shown in the Figs. 6 and 7.

VI. Software Solution for Data Acquisition from Encoders

To implement a software solution we use PCI-6024 card and dedicated MATLAB's toolboxes, SIMULINK and REAL-TIME WINDOWS TARGET, that allow real-time work.

The resolution of encoders is 10,000 pulses per revolution corresponding to a sample time of 0.0001sec. Since the sample time is very small, an external signal is involved to increase sample time up to 0.1sec for data acquisition and computing.

The angular speed of each wheel can be computed using the following relationships:

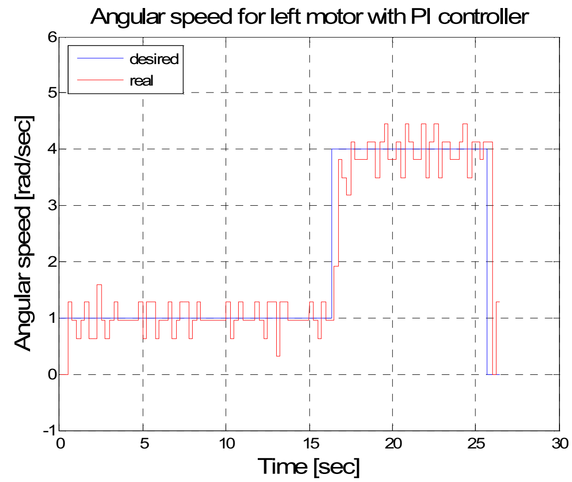

Fig. 6. Closed loop with PI controller, left DC motor angular speed response to a variable step reference input

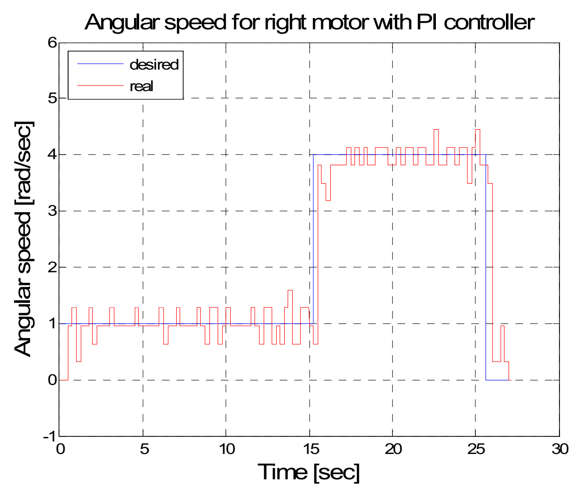

Fig. 7. Closed loop with PI controller, left DC motor angular speed response to a variable step reference input

$$\omega = \frac{\theta_{step} k_{current\ step} - \theta_{step} k_{previous\ step}}{t} \tag{21}$$

$$\theta_{step} = \frac{360^\circ}{number\ of\ pulses\ per\ rotation} \cdot \frac{\pi}{180^\circ} \tag{22}$$

where: θ_{step} is the angle of DC motor shaft, $k_{current\ step}$ is the number of pulses to the current step, $k_{previous\ step}$ is the number of pulses to the previous step, t is sample time. The number of pulses per rotation represents the total number of pulses achieved a complete rotation of the encoder.

In Fig. 8 are shown acquisition data computed by the above formulas.

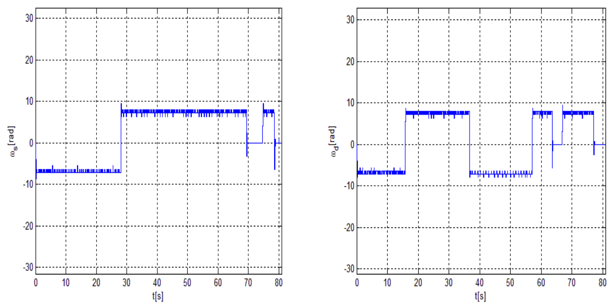

Fig. 8. Real-time data acquisition for left and right DC motor angular speed

VII. Wheelchair Navigation Based on Iris Movement and Image Processing

The navigation system consists of: image processing system, graphic user interface and wheelchair control. Imaging system is to define the controls for steering.

The whole set of information in the image processing [5], [6], [7] includes eye detection, direction finding and validating it by averaging 10 frames. Eye position generates a control signal that can be shaped string forward, left, right, forward direction, left or right or when you want to stop actuators STOP command will be generated by undetected iris eye closure. These commands are sent to the graphical user interface made in LabView programming environment. The steps for identifying the iris and its center are shown in Figure 9.

To identify the direction based on the position of iris circum-center has to measure the center position vs image position along the axis OX (0-320 pixels). When the center of the circle is below 100, the direction will be left; when is over 200, direction is right, and for the center it will take long for intermediate values. The direction signals will be sent to the graphic user interface as strings: FORWARD - for forward direction, LEFT – for left direction, RIGHT – for right direction and STOP – for stopping of the wheelchair. Wheelchair stops when is undetected iris, i.e. eye is closed.

We have defined two safety belts on OY (0 ÷ 240 pixels), an upper in the range (180 ÷ 240) and lower in the range (0 ÷ 40). These strips are designed to filter out false circles that may result from involuntary eye movements. Figure 10 describes the implementation of the solution direction finding by the eye movements of the user.

The graphic user interface, created with a LabVIEW platform, is shown in Fig 11. It was highlighted with red arrows for inactive direction and green for the direction chosen by the user.

When evaluating experimental results and their accuracy, were taken into account a number of factors such as processing power of the computer that equips the wheelchair disturbances in iris identification etc.

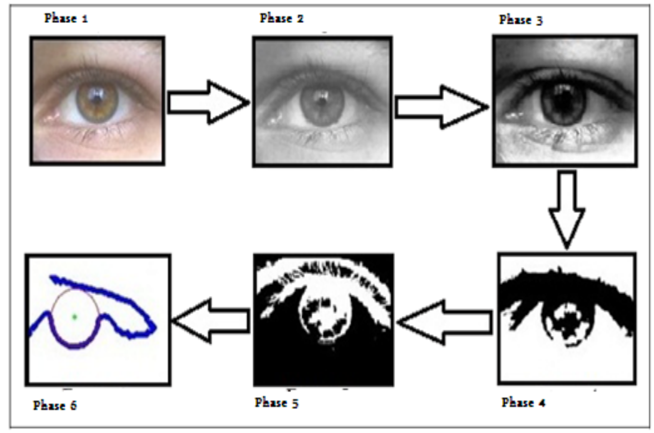

Fig. 9. Phases for iris and its center identification

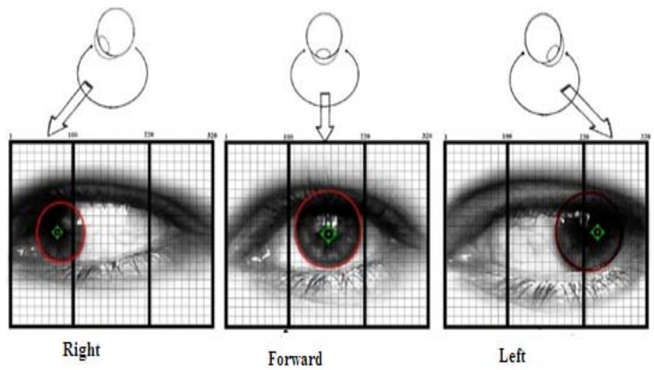

Fig. 10. Method for direction identification

Fig. 11. Graphic user interface for Cirrus Power Wheelchair's control and navigation

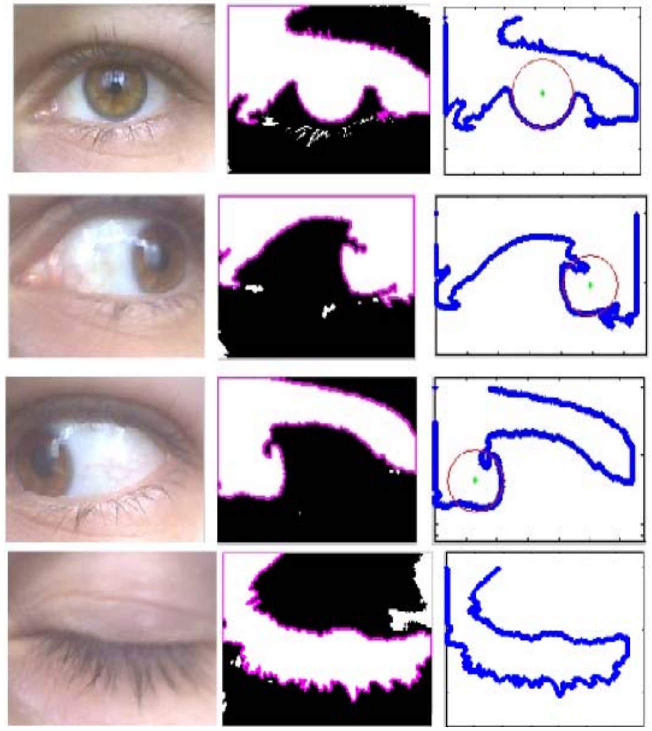

Fig. 12. Wheelchair navigation based on rela-time isris and eye movement

VIII. CONCLUSIONS

Control and navigation of the wheelchair based on kinematic model and image processing of iris movement are presented. The wheelchair is modelled as an WMR autonomous system, with 2DW/2FW. Driving wheel control system are modelled and parameter identified by using MATLAB's System identification toolbox. Pole placement method was used for tuning PI controller parameters. A software solution was proposed for real-time computing of the wheelchair position based on data acquisition from the wheel encoders. A navigation system, based on iris movement and image processing, was implemented by using MATLAB's REAL-TIME WINDOWS TARGET and IMAGE ACQUISITION toolboxes. This navigation system identifies the user's eye movement in three directions: forward, left and right. The eye closing is used for wheelchair stop. Real-time control and navigation results have presented on Cirrus Power Wheelchair.

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