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The Dynamics of a Highly Manoeuvrable Wheelchair

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Abstract **:** This paper concerns the dynamic behaviour of an electrically powered wheelchair . This wheelchair has additional motors which can rotate the driving wheels about a vertical axis. In this way sideways motion and turning on the spot are possible in addition to the conventional forward and turn mode of manoeuvre. The latter two modes of operation are studied in this interim study. The simulated responses are a fair representation of the observed motion of the wheelchair, and indicate that the model can be used to improve the performance of the prototype wheelchair .
Keywords : powered wheelchair; highly manoeuvrable ;

Introduction

There are in the UK an estimated 500,000 wheelchair users; about 5000 use electrically powered chairs, principally for indoor use (Kelsall,1993). Some chairs are reported to be very hard or even impossible to manoeuvre in the close confines of a house.(Sanderson,2000).
Moreover, the Muscular Dystrophy Group estimated that a possible 40,000 adults and children in the UK who would benefit from having an indoor/outdoor powered wheelchair.
Paraplegics with strong arm capability can enjoy playing basketball and tennis using a manual wheelchairs, which can be spun in the spot. However, users without arm strength or control cannot use a conventional powered chair in this manner.

Special wheel designs have been produced to admit traction in one direction while allowing passive motion in another (Borenstein,1996; Yu,2000). These designs can be complex and over-constrained, making control difficult.

This problem has led Bath Institute of Medical Engineering to design and build a relatively simple manoeuvrable powered chair for indoor and outdoor use. The key element in the design is the addition of an extra motors to rotate the driving wheels about a vertical axis, which enables the chair to spin on the spot if required. Sideways motion is achieved by rotating the drive wheel through ninety degrees about the vertical axis. In order to achieve improved performance, a dynamic model of the chair has been developed.

Nomenclature

a half front track of chair
b castor – cg
c wheels – cg
d half rear track of chair
e trail of castor
F_m tractive force at wheel
F_n castor tangential force
F_s castor side force
F_{WCL} wheel side force
h minor offset of wheel force
k integral control constant
r major offset of wheel force
v velocity
x lateral axis, pos right
y longitudinal axis, pos forward
α proportional control constant
ε rotation error $\theta - \theta_d$
θ rotation of chair
ψ rotation angle of wheels

Theoretical Model

The geometry of wheelchair in its conventional mode is indicated in Fig. 1. The rear wheels W_1 and W_2 are powered, and can also be rotated about the vertical axis to give high manoeuvrability. The chair is shown in the conventional configuration.

There are castored wheels at the front, pivoting about O_1 and O_2 .The angle of castor j to the y direction is denoted by φ_j (j =1,2)

The movement of the chair is described in terms of lateral , longitudinal and rotational motions x,y and θ about the centre of mass .

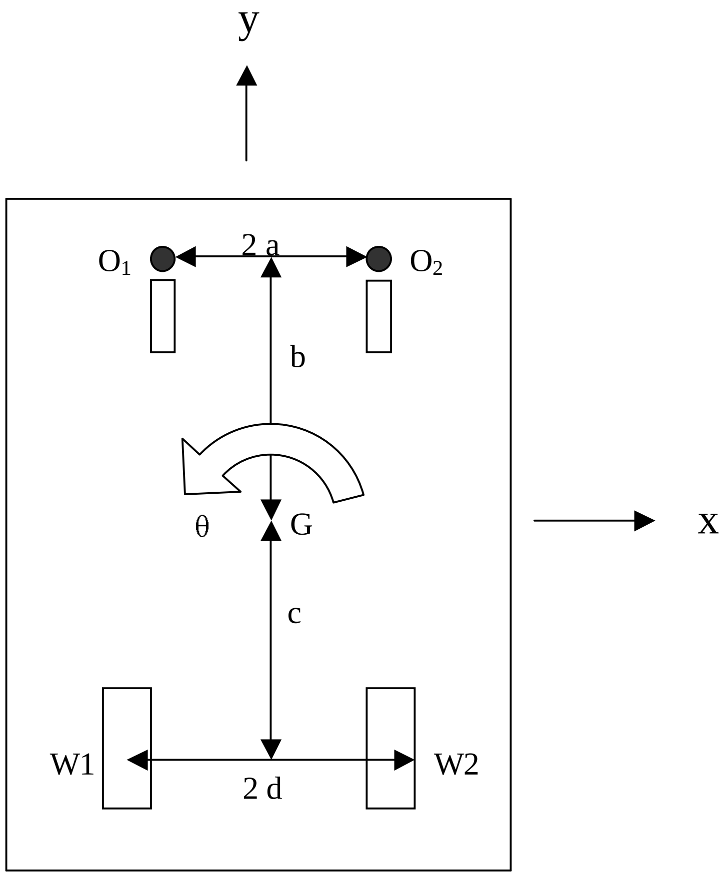
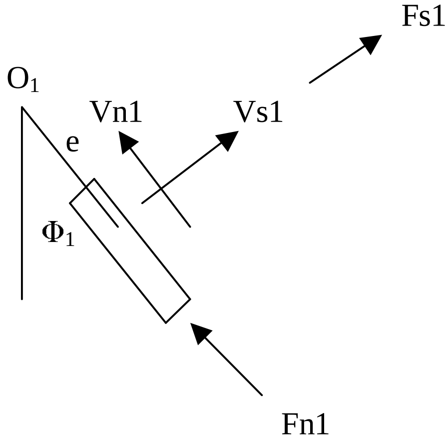


Figure 1. Wheelchair – conventional mode

Figure 2 Castor forces , castor 1



Castor motion

For castor 1 (see Fig. 2) the tangential and lateral velocities are

$v_{n1} = v_{y1} \cos \varphi_1 – v_{x1} \sin \varphi_1$
$v_{s1} = v_{x1} \cos \varphi_1 + v_{y1} \sin \varphi_1 + e\, d\varphi_1/dt$

where $v_{x1}=dx/dt-a\, d\theta/dt$ and $v_{y1}=dy/dt-b\, d\theta/dt$

rolling resistance generates a tangential force $F_{n1}= -c_r N_1$ sign(vn1)
where c_r is typically 0.02.
the sideforce is assumed to be $Fs1= -\mu N_1$ sign(v_{s1})

Allowing a friction torque T_f about the bearing at O_1, the equation of motion for the castor is

$$I_c\, d^2\varphi_1/d t^2 = eF_{s1} - T_f\, \text{sign}(d\varphi_1/dt) \qquad (1)$$

where $e = O_1E$

A similar equation

$$I_c\, d^2\varphi_2/d t^2 = eF_{s2} - T_f\, \text{sign}(d\varphi_2/dt) \qquad (2)$$

governs the motion φ_2 of the other castor about O_2; $v_{y2} = dy/dt + b\, d\theta/dt$

Steering Control

Given a demand direction θ_d set by the joystick, the controller used is

$Fm1=F_{m10}\, (1+\alpha\, \varepsilon + k \int \varepsilon\, dt)$; $F_{m2} = F_{m20}\, (1-\alpha\, \varepsilon - k \int \varepsilon\, dt\,)$

where ε is the error $\theta - \theta_d$

In the manual mode inputs are only made at discrete instants (e.g. at 0,1s, 1.5 s..) and the integral component is not used.

Given tractive forces F_{m1} and F_{m2} at wheels 1 and 2 respectively, the equations of motion for longitudinal (forward) and sideways (lateral) motion are

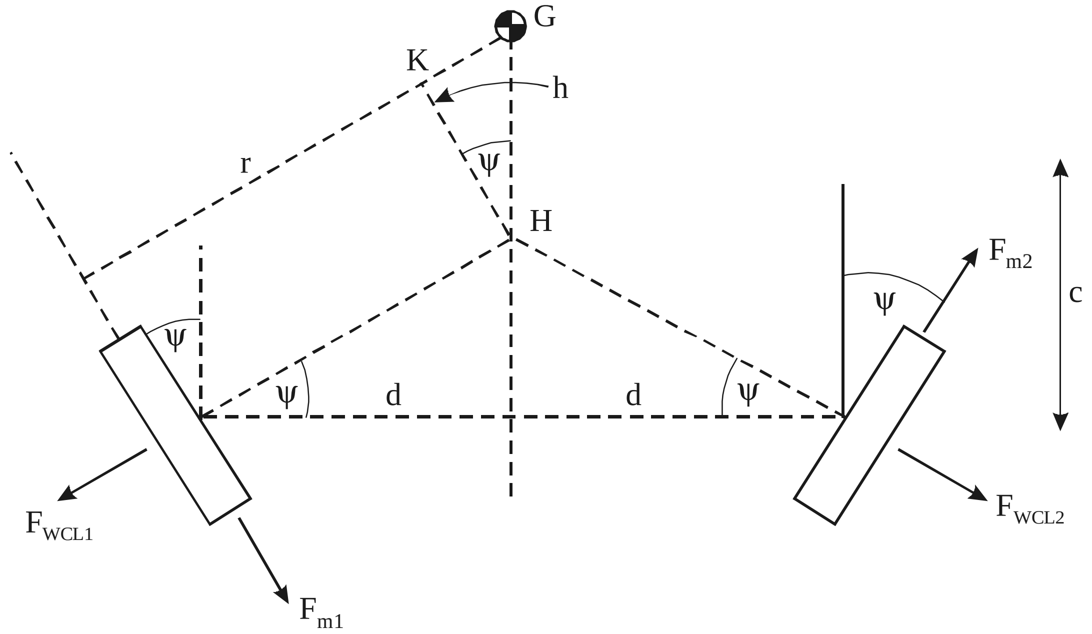
$$M\, d^2y/dt^2 = F_{m1} + F_{m2} - Fn1 \cos \varphi_1 + F_{s1} \sin \varphi_1 - F_{n2} \cos \varphi_2 + F_{s2} \sin \varphi_2 \qquad (3)$$

$$M\, d^2x/dt^2 = F_{L1} + F_{L2} + F_{n1} \sin \varphi_1 + F_{s1} \cos \varphi_1 + F_{n2} \sin \varphi_2 + F_{s2} \cos \varphi_2 \qquad (4)$$

while rotation is given by

$$I_{wc} d^2\theta/dt^2 = d(F_{m2} – F_{m1}) + b(Fn1 \cos \varphi_1 - F_{s1} \sin \varphi_1) – b(F_{n2} \cos \varphi_2 - F_{s2} \sin \varphi_2)$$
$$-a(F_{n1} \sin \varphi_1 + F_{s1} \cos \varphi_1 + F_{n2} \sin \varphi_2 + F_{s2} \cos \varphi_2) + c(F_{L1} + F_{L2}) \qquad (5)$$

The response is obtained from equations (1) to (5)



<u>General Maneouvre</u>

In the general case the driving wheels are aligned at an angle ψ to the longitudinal axis.(Fig. 3). The wheels are rotated in opposite senses to produce rotation . Only in the particular case of $\tan\psi = c/d$ do the traction forces produce pure rotation.

The moment about G is $r(F_{m1}+F_{m2}) + h(F_{WCL2} - F_{WCL1})$
where $r = d/\cos\psi + KG = d/\cos\psi + (c-d\tan\psi)\sin\psi$
and $h = GH\cos\psi = (c-d\tan\psi)\cos\psi$

The tangential velocities (along the line of the wheel) are
$v_{tWC1} = r\, d\theta/dt - \cos\psi\, dy.dt + \sin\psi dx/dt$
$v_{tWC2} = r\, d\theta/dt + \cos\psi\, dy.dt + \sin\psi dx/dt$

and normal to the wheel
$v_{nWC1} = -h\, d\theta/dt - \sin\psi\, dy/dt - \cos\psi\, dx/dt$
$v_{nWC2} = h\, d\theta/dt - \sin\psi\, dy/dt + \cos\psi\, dx/dt$

The slip angles v_{nWC1}/ v_{tWC1} and v_{nWC2}/ v_{tWC2} .The side forces are calculated in the same way as those on the castors.

Results

The parameter values for the chair are
M= 150 kg; $N_1 = N_2 = 367.9$ Newtons; $I_{wc} = 0.5$ kg m^2
$I_c = 0.1$ kgm^2 ; T_f= 5 Nm; T_{fr}= 0.02; $\mu = \mu_c$ 0.08
a=0.3787 m, b=0.3m,c=0.26m,d=0.205m, e=0.0552m

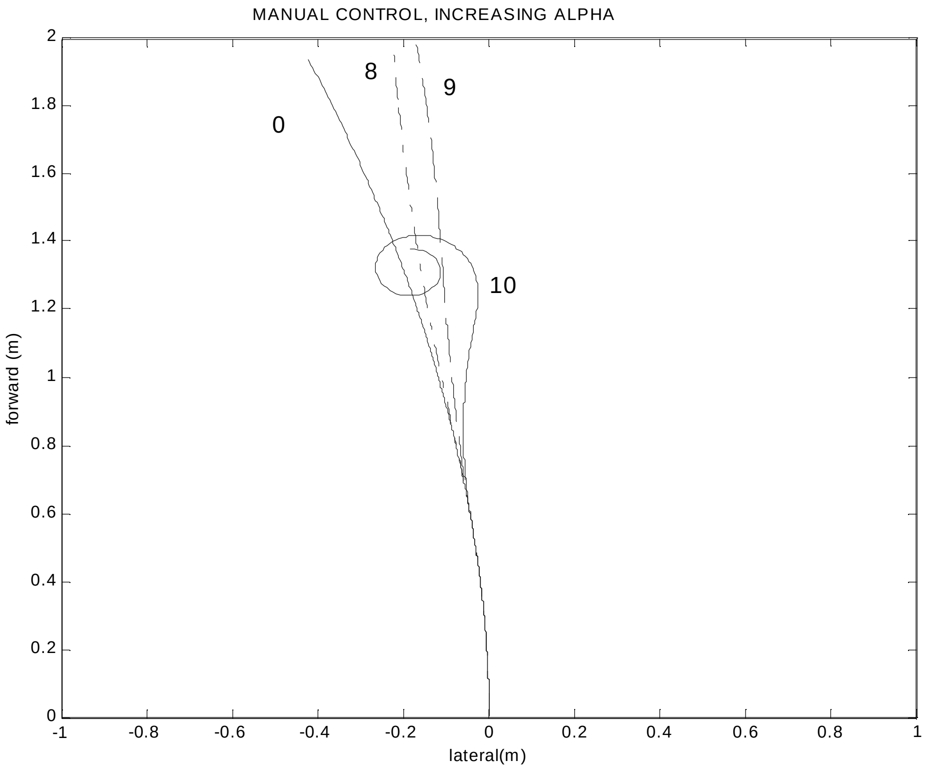


Figure 4. Lateral drift due to castor misalignment;
α = 0,8,9,10

Forward motion of the chair was simulated for initial castor angles or 10 degrees and 1 degrees. The response with and without directional control is shown in Fig. 4. The notional tractive force on each wheel was 75N. As the proportional control term α is increased the directional error falls up to a value of 9. Beyond this instability results.

The corresponding plot of chair rotation is shown in Fig. 5. The directional instability is marked.

Conclusions and Further Work

- The model produces responses which are in fair agreement with the observed response of the wheelchair itself.
- Directional control can be achieved but instability results if the gain is too high
- A more detailed model for the lateral wheel forces, based on car tyre behaviour, will be examined, as will purely lateral motion

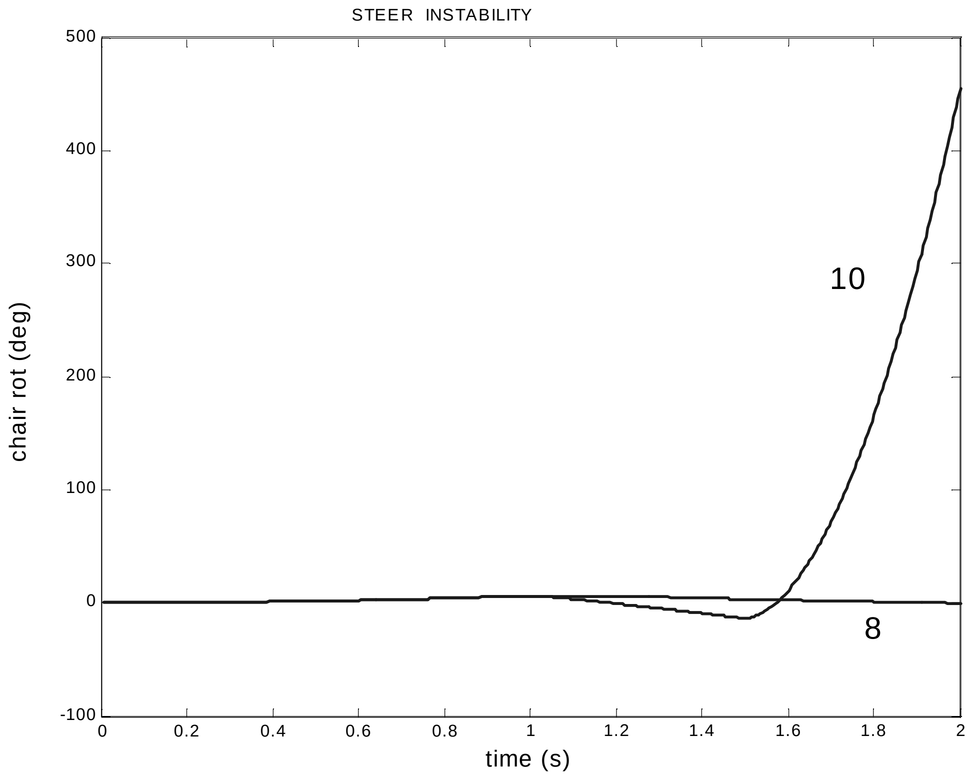


Figure 5. Directional instability

Responsibility notice

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