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Designing of Unmanned Ground Vehicle

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***Abstract*—An unmanned ground vehicle (UGV) is mechanized equipment that moves across the any surface of the ground (terrain) without intervention of human. Being autonomous in nature, UGVs are capable of operating over a wide variety of terrain, operating condition. Hence robust and precise control of UGV is required. For developing a robust control strategy it is necessary to have an accurate mathematical model of UGV. In this paper, nonlinear mathematical model of UGV for straight and turning motion is presented and is implemented in MATLAB environment with various subsystems. Thereafter transfer function model of UGV is obtained by linearizing. Using this linearized transfer function model conventional proportional integral derivative (PID) controller are designed and applied to nonlinear model of UGV. Simulation results are generated for various transient conditions and disturbance levels.**

***Keywords*—Mathematical modeling, Unmanned ground all terrain vehicle, PID controller.**

I. INTRODUCTION

The UGV is shown in figure 1. The Vehicle has many nonlinear subsystems. The unmanned ground UGV) are always nonlinear as it has many subsystems which are nonlinear. Mathematical modeling will give proper idle for controlling purpose.

Figure 1 UGV

Most UGVs are currently teleoperated machines which require human intervention, thus, the range of applications is limited. Therefore, knowledge of the interaction between UGVs and terrain plays an important role to design a controller and design of controller requires nonlinear mathematical modeling of UGV.

In this paper, detailed mathematical model of UGV, obtained from various subsystems is presented. All these subsystems are combined in MATLAB/ Simulink software to form a complete UGV system. A linear TF model is then obtained and PID controller are designed which are applied to nonlinear UGV.

II. MODELLING OF UNMANNED GROUND VEHICLE

A nonlinear model of UGV consist of the engine, continuous variable transmission (CVT), gearbox, differential, chains and wheel as shown in Fig 1.1.

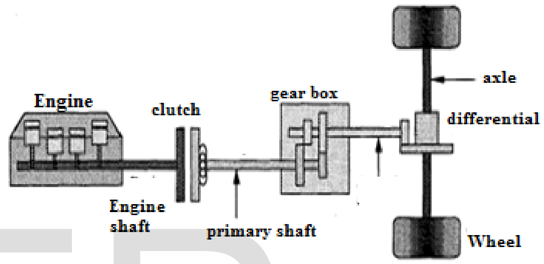

Fig. 1.1. Subsystem of UGV

Mathematical model of various subsystems are given below

A. Engine

Enginecanbemodeledasafirst-order transfer function[1] such that

$$T_e = \frac{K_e}{\tau_e s + 1}\theta_e \qquad (1)$$

For notations and symbols refer nomenclatures
The engine motion equationisthen given by

$$J_e\dot{\omega}_e = T_e - T_{fric_e} - T_{ec} \qquad (2)$$

where

$$T_{fric_e} = b_e\omega_e \qquad (3)$$

Above equations can be implemented in MATLAB as shown in fig 2 as engine subsystem.

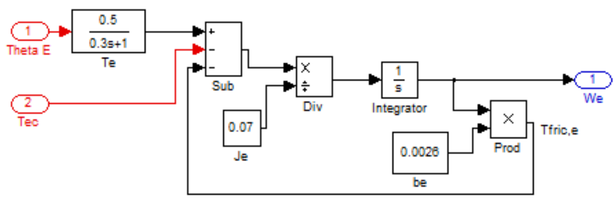

Fig. 2 Engine Subsystem

B. CVT

CTV is automatic torque converter, it has a driver clutch located on the engine output shaft as shown in fig 1[1].The CVT can be modeled as a variable gear ratio, which depends on the engine speed and load torque as mentioned below

$$K_1 = f(\omega_e, T_e) = g(\omega_e)h(T_c) \tag{4}$$

$$g(\omega_e) = \begin{cases} \frac{1}{2500}(\omega_e - 89.01), \omega_e \geq 89.01rad/s \\ 0\,, \qquad \omega_e < 89.01rad/s \end{cases} \tag{5}$$

$$h(T_c) = \begin{cases} \frac{1}{500}(500 - T_c), \quad if\ T_c \leq 500Nm \\ 0, \qquad if\ T_c \geq 500\ Nm \end{cases} \tag{6}$$

The speed of CTV and torque fromthe CVT acting on the engine are written as

$$\omega_c = \omega_e K_1 \tag{7}$$

$$T_{ec} = T_c K_1 \tag{8}$$

Function (5-6) along with equation (7-8) are modeled in MATLAB as illustrated in fig 3

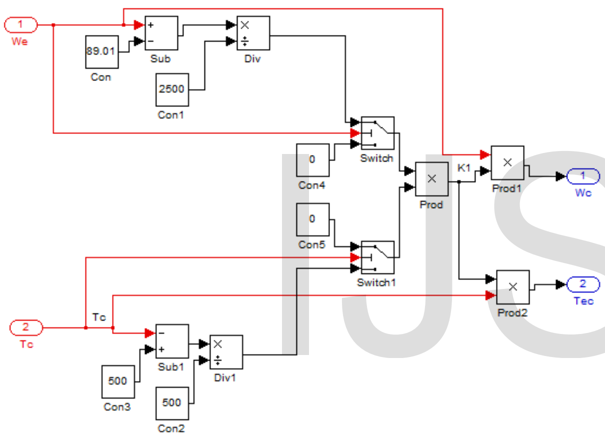

Fig. 3 CTV Subsystem

C. Gearbox

The gearbox engages directly to the case (ring gear) of the differential [1]. Therefore, the differential's case can be considered as the output of the gearbox when calculating the gearbox ratio, K_2The torque and speed atthe output ofthe gearboxare calculated as

$$T_G = \frac{\left(T_c - T_{fric\ G}\right)}{K_2} \tag{9}$$

$$\omega_G = \omega_c K_2 \tag{10}$$

$$T_{fric\ G} = b_G \omega_c \tag{11}$$

Fig 4 presents the realization of (9-11) in MATLAB

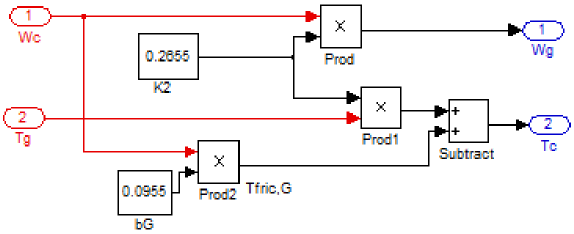

Fig. 4 Gearbox Subsystem

D. Differential

The left and right wheel movements are controlled by differential[1].The torque difference enables the vehicle to turn.The speed and torque of differential for straight path are given as

$$\omega_d = \omega_G \tag{12}$$

$$T_d = T_G - T_{fric\ d} \tag{13}$$

$$T_{fric\ d} = b_d \omega_G \tag{14}$$

The speed and torque of differential for turning path are written as

$$\omega_{dR} = \omega_G - X \tag{15}$$

$$\omega_{dL} = \omega_G + X$$

where

$$X = (T_{SR} - T_{SL})/b_{d,in} \tag{16}$$

$$T_{SR} = T_{dR} + T_{bR}$$

$$T_{SL} = T_{dL} + T_{bL}$$

Equation (12-14) and (15-16) are combined to form straight path model and turning path model of UGV in MATLAB as shown in fig 5

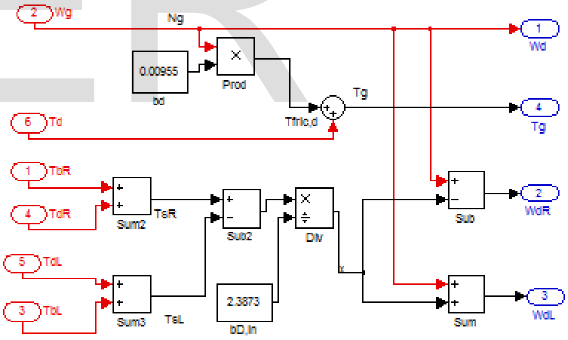

Fig. 5Differential subsystem for straight path and turning motion

E. Chain

Thechainsystemcanbesimplifiedasagearratio$K3$. The wheel speed and differential torque is give as below

$$\omega_w = K_3 \omega_d \tag{17}$$

$$T_d = K_3 T_w \tag{18}$$

The speed of right and left wheeland torque of differential is specified as in equation (17-22) and implantation shown in fig 6

$$\omega_{wR} = K_3 \omega_{dR} \tag{19}$$

$$\omega_{wL} = K_3 \omega_{dL} \tag{20}$$

$$T_{dR} = K_3 T_{wR} \tag{21}$$

$$T_{dL} = K_3 T_{wL} \tag{22}$$

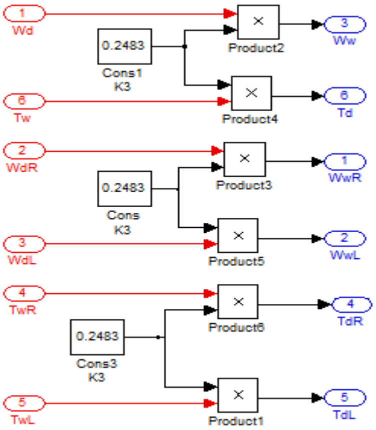

Fig. 6 Chain Subsystem for turning

F. Wheel

Alldrivewheelscanbecombinedand modeledasonewheel [1].Thetotalloadtorqueactingonthewheelshaftincludesthetorquerequiredfortraction, the torque due to internal friction, andthetorqueforwheel acceleration as written in equation (23)

$$\omega_w = J_w \dot{\omega_w} + T_{fric_w} + r\, F_{t_w} \quad (23)$$

$$T_{fric_w} = b_w \omega_w \quad (24)$$

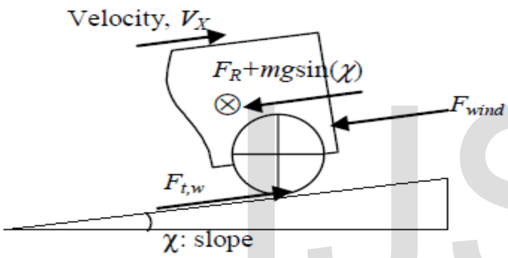

Fig. 7Force acting of vehicle during running

$$F_{t_w} = m\dot{V_x} + F_{wind} + F_R + mgsin(x) \quad (25)$$

The air dragforce,F_{wind}, can be ignored as the vehicleruns atlow speed.

$$F_R = m(C_{r_1} + C_{r_2} V_x) \quad (26)$$

Wheel velocity is given as

$$V_x = r\omega_w \quad (26)$$

Wheel torque is give below from equation (23-26)

$$T_w = (J_w + mr^2)\dot{\omega_w} + T_{fric_w} + mr(C_{r_1} + C_{r_2} r\omega_w) + mgrsin(x) \quad (27)$$

Torque of right and left wheel for straight path and turning motion (27-29) and realized in MATLAB shown in fig 8

$$T_{wR} = \frac{1}{2}(J_w + mr^2)\dot{\omega_w} + T_{fric_w} + \frac{1}{2}mr(C_{r_1} + C_{r_2} r\omega_w) + \frac{1}{2}mgrsin(x) \quad (28)$$

$$T_{wL} = \frac{1}{2}(J_w + mr^2)\dot{\omega_w} + T_{fric_w} + \frac{1}{2}mr(C_{r_1} + C_{r_2} r\omega_w) + \frac{1}{2}mgrsin(x) \quad (29)$$

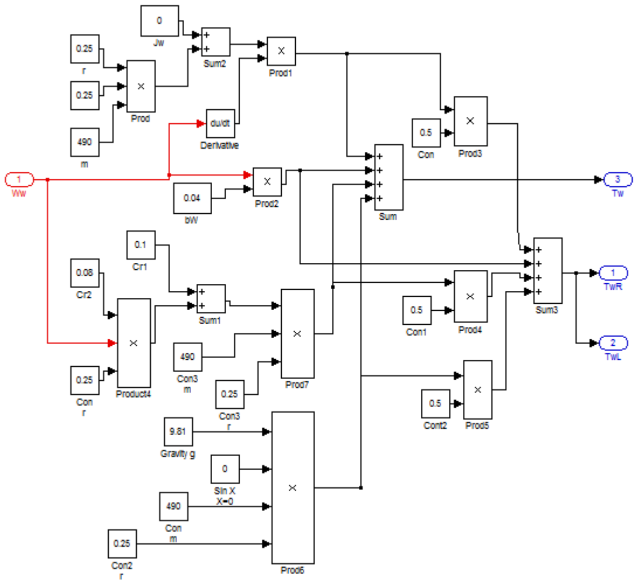

Fig. 8 Wheel subsystem for straight path and turning motion

Consider TF as follow

$$Tf = \frac{\omega_w}{\theta_e} = \frac{0.44}{S^2 + 2.004S + 0.7994} \quad (39)$$

B. Design of PID controller

Table 2 PID tuning parameter

Tuning Technique	Controller	Kc	τ_i	τ_d
ZNOL- SP	PI	12.10	4.65	----
	PID	19.22	5.26	2.76
ZNOL-LDR	PI	14.07	20.69	----
	PID	24.27	40.80	3.0111

III. Simulation Results

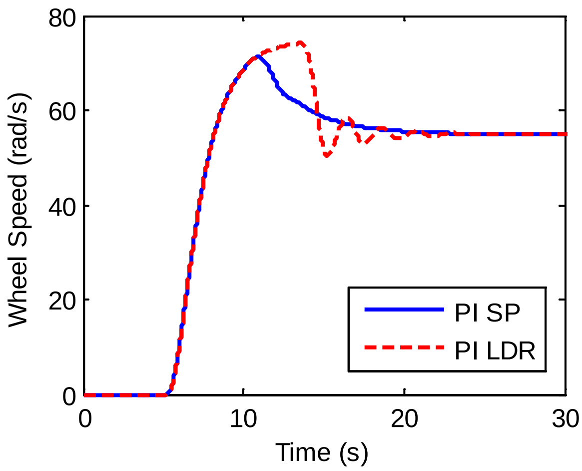

Fig. 9Variation in wheel speed

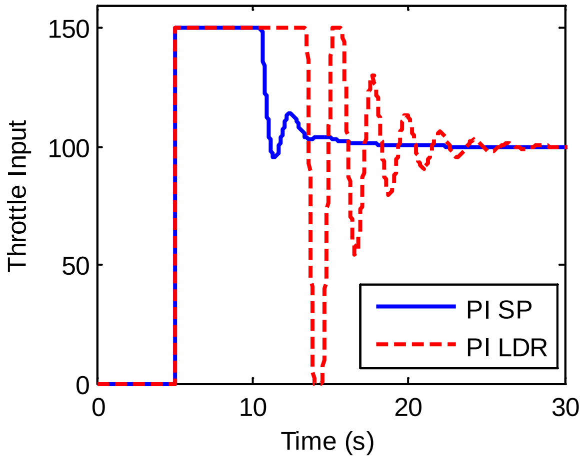

Fig. 10Variation in throttle input

Controller	%M_P	t_P(s)	t_s(s)	t_r(s)
ZNOL PI SP	18.94	15.6417	22.1317	2.4858
ZNOL PI LDR	19.16	19.5055	23.6808	2.4858

IV. Conclusion

In this paper nonlinear UGV is modeled by considering all possible non linearity. It is believed that the study carried out in this paper is useful for modeling nonlinear UGVand help to select appropriate controller for nonlinearUGV.

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Nomenclature:-

		Subscripes	
J	Moment of innertial kg/m^2	c	CTV
K	Gain, Constant	d	Differential
ω	Speed (rad/s)	e	Engine
S	Laplace oprator	G	Gearbox
T	Torque (N/m)	r1	Tyre friction
V	Velocity (m/s)	r2	Road friction
b	Friction coeficient	w	Wheel
c	Friction coefficient	bL	Left break
g	Acceration to gravity (m/s^2)	bR	Right break
m	Mass (kg)	dL	Differential left
r	Wheel radius (m)	g(.)	Fuction of speed
θ	Throttle Input	h(.)	Fuction of torque
τ	Time consatnt	fric	friction
		ec	CTV to engine