Traction Force Improvement of a Two Wheel Mobile Manipulator by Changing the Centre of Gravity

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***Abstract*— In this paper, a traction control method for a two wheel mobile robot is presented. Traction force acting on a wheel is dependent upon the dynamic frictional coefficient and the reaction force acting on each wheel. It is proposed to obtain the maximum traction force by selecting the best value for slip percentage as well as selecting a suitable value for the reaction force. Reaction force variation is achieved by changing the centre of gravity (COG) of the mobile robot. Two electric motors are used to drive the two wheel manipulator.**

***Index Terms*— traction control, mobile robot, slip, driving force, centre of gravity**

I. INTRODUCTION

Today the Electric wheeled manipulators are extensively used in outer space experiments and places where humans are not easily accessible. When compared to the engine driven option electric motors are much easily controllable. Motor torque generation is quick and accurate. Further motors can be fixed to each wheel unlike engines.

Many experiments have been done regarding the vehicle slip phenomena. Y. Hori and others have implemented traction control strategy based on regulation of desired slip ratio decided by the road condition estimator [2],[3]. Unfortunately these strategies are designed for high speed vehicles like cars. Road condition estimation algorithm is similar to the estimator proposed by [2]. However it is customised for two wheeled low speed mobile robot. Changing the centre of gravity is proposed to maximise the traction force.

There are some basic differences between mobile manipulators (MM) and electric vehicles (EV). Usually EVs are expected to travel longer distances. Driver is expected to command the EV using an accelerating command. EVs are made to achieve high speeds. In contrary MMs are made to travel shorter distances at relatively low speed. MMs are normally used do specific tasks like outer space experiments. MMs can be commanded real-time like in a EV or a path can be commanded to follow.

There are several advantages of improving the traction force. Slip can be changed or controlled by changing the traction force. Improving the traction force will increase the load that the mobile robot can transport. On the other hand mobile robot can be designed with lesser weight if the traction force can be maximised.

If the mobile manipulator is expected to travel autonomously in a changing terrain, slip can affect the traction force. In this paper, we present a traction control system for a two wheel mobile manipulator. Primary objective of this research is to achieve the maximum possible traction force.

II. TRACTION CONTROL

When a manipulator is moving, sliding and driving forces are acting on it. When the slip of the wheels is high, manipulator tends to slide. Slide force takes its maximum value when the slip is zero. When the slip is increasing, the slide force decreases exponentially. However the effect of sliding is very less since mobile manipulators are not expected to move at a very high speed. Therefore, in this paper, slipping control is only discussed.

Slip ratio λ is defined as follows where Vw is the wheel speed and V is the vehicle ground speed.

$$\lambda = (Vw - V)/\, Vw \tag{1}$$

Fig.1 shows the typical shape of the Friction coefficient - slip ratio (μ-λ) curve for two different terrains.

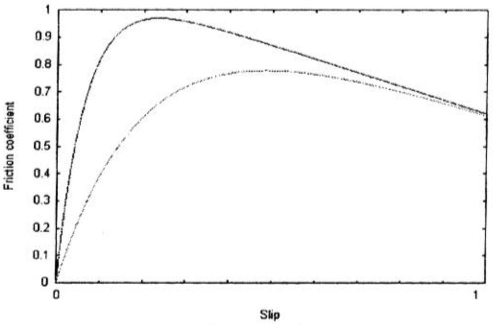

Fig.1. (μ-λ) curves

As for the above figure, it can be noted that when the slip ratio increases dynamic frictional coefficient μ also increases. Then it starts decreasing from the maximum point. If there is a method to operate at this maximum μ, mobile manipulators can achieve the maximum traction force provided that there is no change in the wheel reaction force.

Friction force exchanged by the wheel and the road is given by the equation (2).

$$F = N\,\mu(Slip) \tag{2}$$

Where F is the traction force and N is the normal force (reaction force) acting on the wheel. μ(Slip) is the friction coefficient corresponding to the slip as of the μ - λ curve.

As for equation (2) traction force is a function of N and μ(Slip). When N is a constant, F can be maximized by selecting the optimum μ(Slip). When N is a variable, both optimum μ(Slip) and N maximizes the traction force.

III. CONSTRUCTION

A. *Physical Construction*

The main objective of this research is to achieve maximum traction force. This is achieved through changing centre of gravity location and locating the optimum slip, which gives the highest traction.

For this research two wheeled mobile manipulator is used. Both wheels are driven separately by two DC motors. Both motors can be controlled independently. Ground speed is measured using a non-driven wheel. Wheel speed is measured using two rotary encoders which are attached to the wheels. Changing the gravity location is achieved through the manipulation of an arm, which is already attached to the mobile robot.

B. *Kinematics*

Kinematics model, which is used, is shown in Fig .2

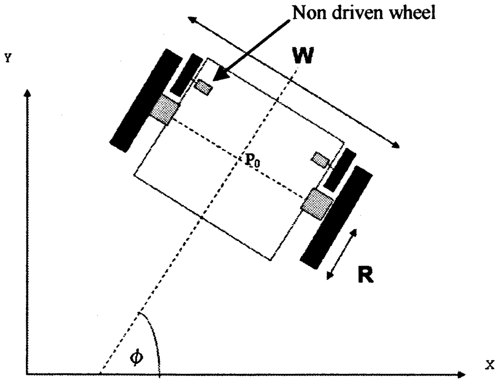

Fig .2. Kinematics model -world coordinate

W: Thread of the robot
R : Radius of driving wheel
ϕ : Attitude angle

Angle of rotation of right and left wheels can be represented as equation (3).

$$\theta = [\theta_r, \theta_l]^T \tag{3}$$

Position and attitude angle can be represented as (4)

$$X = [x, y, \phi]^T \tag{4}$$

Then the direct kinematics equation can be represented as (5)

$$\begin{bmatrix} \dot{x}_0 \\ \dot{y}_0 \\ \dot{\phi}_0 \end{bmatrix} = \begin{bmatrix} \frac{R\cos\phi}{2} & \frac{R\cos\phi}{2} \\ \frac{R\sin\phi}{2} & \frac{R\sin\phi}{2} \\ \frac{R}{W} & \frac{R}{W} \end{bmatrix} \begin{bmatrix} \dot{\theta}_r \\ \dot{\theta}_l \end{bmatrix} \tag{5}$$

where Jacobian matrix J is represented as (6)

$$J = \begin{bmatrix} \frac{R\cos\phi}{2} & \frac{R\cos\phi}{2} \\ \frac{R\sin\phi}{2} & \frac{R\sin\phi}{2} \\ \frac{R}{W} & \frac{R}{W} \end{bmatrix} \tag{6}$$

In order to calculate inverse kinematic equations, (5) is differentiated and (8) can be obtained where

$$Jaco^{+} = \frac{1}{R} \cdot \begin{bmatrix} \cos\phi & \sin\phi & \frac{W}{2} \\ \cos\phi & \sin\phi & \frac{-W}{2} \end{bmatrix} \tag{7}$$

$$\ddot{\theta} = J^{+}_{aco}(\phi).\ddot{X} + \dot{J}^{+}_{aco}(\phi).\dot{X} \tag{8}$$

By neglecting the inverse Jacobean derivative, (9) can be obtained.

$$\ddot{\theta} = J^{+}_{aco}(\phi).\ddot{X} \tag{9}$$

C *Dynamics*

Dynamics of the mobile robot can be described as follows. Torques of right and left wheels can be calculated as follows.

$$\begin{bmatrix} \tau_r \\ \tau_l \end{bmatrix} = M_{\theta} \cdot \begin{bmatrix} \ddot{\theta}_r \\ \ddot{\theta}_l \end{bmatrix} \tag{10}$$

Here

$$M_{\theta} = \begin{bmatrix} \frac{M}{4} + \frac{J}{W^2} + \frac{J_W}{R^2} & \frac{M}{4} - \frac{J}{W^2} \\ \frac{M}{4} - \frac{J}{W^2} & \frac{M}{4} + \frac{J}{W^2} + \frac{J_W}{R^2} \end{bmatrix} \tag{11}$$

M : Mass of the mobile robot
J : Inertia of mobile robot around axis vertical to x-y plane
J_W : Inertia of each wheel

D Dead-Reckoning

In order to estimate position and attitude dead-reckoning is used. Estimated values of x and y positions are found as follows.

$$x_k = x_{k-1} + v.\cos\left(\frac{\phi_k + \phi_{k-1}}{2}\right)\cdot \Delta t \qquad (12)$$

$$y_k = y_{k-1} + v.\sin\left(\frac{\phi_k + \phi_{k-1}}{2}\right)\cdot \Delta t \qquad (13)$$

Here
Subscript k indicates their values at time k and subscript k-1 indicates their values at time k-1.

v : velocity of the robot in world coordinate at time k
Δt : Sampling time

Attitude angle is calculated as follows.

$$\phi = \frac{R}{W}.(\theta_r - \theta_l) \qquad (14)$$

IV. CONTROL SYSTEM

Block diagram of the control system is shown in the Fig. 3. for the left wheel..

A. Low Select and Trajectory Logic

According to the user input, system calculates, T_{com}. According to the slip conditions, the maximum possible torque which optimizes the traction is fed from PI controller. Low select function selects the lower value among Tcom and T pro. If the manipulator is following a cornering path, command values for left and right wheels are different. If low select function selects the Tpro. It does not contain any path information unlike Tcom. In that case trajectory logic is there to preserve the path information. Trajectory logic scales down the torques according to the left and right wheel angular accelerating commands.

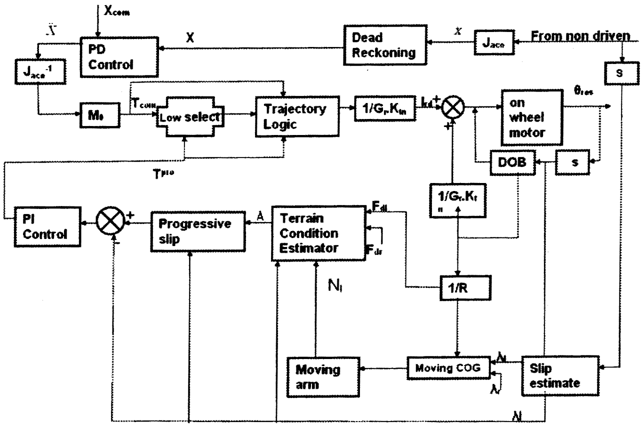

Fig.3. Control Block diagram

B. On wheel motor and Disturbance observer

Each on wheel motor incorporates a disturbance observer. This serves two purposes. First one is to compensate the modelling errors and external disturbances. Second purpose is to estimate the disturbance torque which is proportional to the driving force acting on the wheel. When the disturbance torque is divided by the wheel radius, driving force can be estimated.

C. Slip Estimate

Slip ratio can be easily calculated from the non driven wheel input and the on wheel motor output.

D. Moving COG

Moving COG controller commands the arm such that it will tilt according to the command. Driving forces of both left and right wheels are used in moving the COG.

Driving forces can not be used directly to move COG. If command current for both left and right wheels are equal, driving forces can be used as a measure of slip. But in practice, when the manipulator is turning, command current for left and right wheels are different. Therefore difference of the driving forces will not show a slip. To eliminate this problem ratio between driving force and current command will be used as a measure of slip. Instead of using this driving force information, slip rations can be directly used to move the COG. If the left wheel slips or if the left wheel slip is more than the right wheel, moving arm is commanded to move towards left wheel to increase the reaction force acting on that wheel. This will decrease the reaction force acting on the right wheel. Moving arm settles in a position where there is less difference between the slips.

E. Moving arm

Reaction force variation is modeled using the following simple manipulator model. Forces on two wheels are Nl and Nr. Width of the manipulator is “a”. Weight of the vehicle except the moving arm is considered as “mg”. Weight of the moving arm is considered as “Mg”. Mg is acting “x” distance away as shown in the diagram.

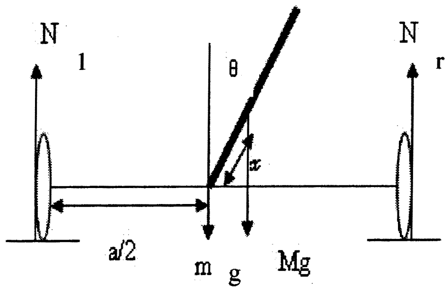

Fig.4 Normal force variation

As the θ varies, Nl and Nr values will be changed according to the following equations.

$$N_l + N_r = (m+M)g \quad (14)$$

$$a/2.mg + (a/2 + x\sin\theta)\, Mg = aN_r \quad (15)$$

Fig (5) shows the normal force variation of both wheels with the arm angle. Sinusoidal force variation can be observed for -90 to +90 degrees of tilt. As for the diagram and the equations above, variation can be increased by adding more weight to the moving arm. In other words, adding more weight at the end of the arm would increase x, which intern increases the force variation.

It is expected to move the arm within -60 to +60 degrees rather than moving from -90 to +90. Last 30 degrees is not much productive in terms of force variation.

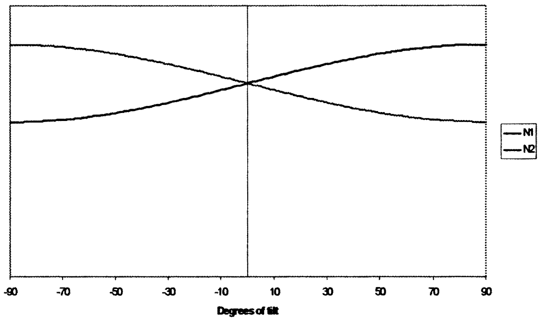

Fig.5. Normal force variation

F. Terrain condition estimator

If the moving arm position is known, the reaction force acting on each wheel can be calculated as shown before. Driving force can be calculated from the disturbance observer.

Dynamic frictional coefficient can be calculated as follows.

$$\mu(Slip) = \frac{\text{Driving force on the wheel}}{\text{Reaction force on wheel}} \quad (16)$$

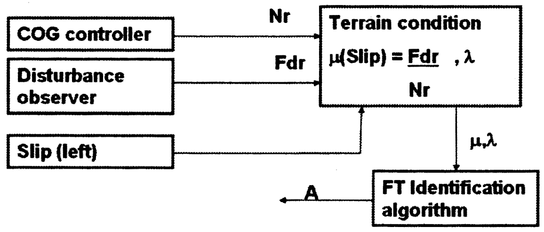

Fig.6. Terrain Condition estimation

Gradient of μ-λ curve A is defined as follows.

$$A = \frac{d\mu}{d\lambda} \quad (17)$$

To eliminate the effect of sudden changes a well known adaptive identification method, fixed trace (FT) algorithm is used.

G. Progressive slip

As for fig(1) gradient A is positive until the slip reaches the optimal value. A will be negative when the robot is operating on the undesirable region. Therefore progressive slip is a simple optimal slip estimation process. When A is positive it indicates that the current level of optimal slip is more than the present slip. On the other hand when A is negative, optimal slip should be below the present level of slip.

V. SIMULATION RESULTS

Slip changes when the reaction force acting on wheels changes even for a specific terrain. But this relationship is dependent on the tire material, tire air pressure and many factors that are not be practically modelled.

Therefore, a constant slip of 0.1 is given for the left wheel of the robot as shown in Fig.7.

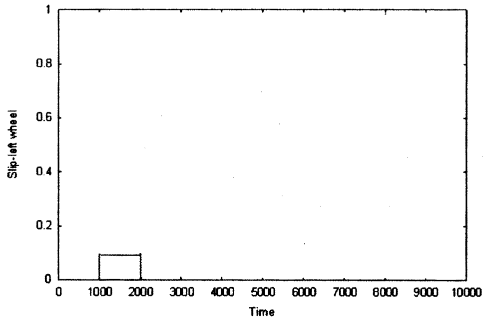

Fig.7. Slip – left wheel

Due to the given constant slip, arm has moved towards left wheel as shown in Fig.8.

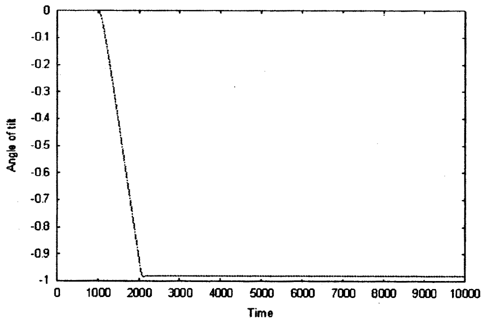

Fig.8.Arm- Angle of tilt

Nr and Nl reaction forces acting on the wheels have changed as shown in Fig.9.

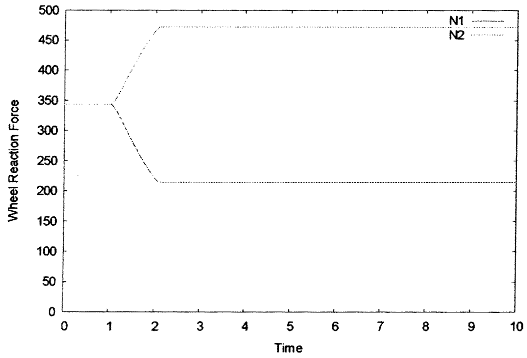

Fig.9. Reaction forces on each wheel

VI. CONCLUSION

In this paper, a method achieve maximum traction force is proposed. Both normal force change as well as the slip control is proposed to be used for the experiment. Novel idea of changing COG is proposed to maximize the traction force. Road condition estimation is already being implemented for electric car. This idea has been customized for two wheel manipulator with the novel idea of changing COG. It is difficult to model the slip variation when the wheel reaction force changes. Constant slip ratio command was given for simulation purposes. However, experiment has to be completed to study more on reaction force-slip relationship.

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