# STUDY ON SENSORLESS LOAD DETECTION OF A MOBILE ROBOT USING DISTURBANCE OBSERVER

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**ABSTRACT**

In this paper, sensorless load detection method for a mobile robot is presented. Torque acting on the wheels is to be calculated using the disturbance observer method. In this method, only the shaft encoders are used as the feedback and no other torque or current sensors are used. To drive the robot, two electric motors are used. When the mobile robot manipulator hits on an obstacle without a jerk and continues to push the obstacle without slipping the wheels, it is proposed to calculate the point of hitting.

## 1. INTRODUCTION

In most cases of robot manipulations calculating the force that exerts on the wheels is essential. Ordinary way to calculate this is the use of Torque sensors or the current sensors. In many of the applications and in some researches springs with potentiometers are used as force sensors [1]. But the problem is that this tend to give noise when operation. With the use of the disturbance observer method, it is possible to calculate the force feedback without any torque sensors. The only feedback device that is used in this method is the encoders. This method is designed in a way that it is possible to estimate the disturbance from the observer [2] [3].

When an electric motor is operating, two kinds of torques are applied on it. They are Motor torque and the Load torque. If the inertia of the load coupled and the rotor is *J*, it is possible to write the motor equation as follows.

$$J\ddot{\theta} = \tau_m - \tau_l$$
(1)

Where,

$\ddot{\theta}$ = Angular acceleration of the Motor

$\tau_m$ = Mechanical Torque

$\tau_l$ = Load Torque

Load torque $\tau_l$ can be written as,

$$\tau_l = \tau_{int} + \tau_{ext} + f + D\dot{\theta}$$
(2)

Here,

$\tau_{int}$ = Inertial Torque

$\tau_{ext}$ = Torque applied from the external to the system

$f$ = Friction torque due to the coulomb effect

$D\dot{\theta}$ = Friction torque due to the viscosity.

For a current controller contains a high gain, input current can be considered as the reference current. Therefore the mechanical torque $\tau_m$ can be written as follows.

$$\tau_m = K_t I_a^{ref}$$
(3)

Where, $K_t$ is the motor constant of the motor.

Therefore the equation 1 can be re written as,

$$J\ddot{\theta} = K_t I_a^{ref} - (\tau_{int} + \tau_{ext} + f + D\dot{\theta})$$
(4)

Inertia of the system *J* can be changed due to the mechanical configuration of the system.

$$J = J_n - \Delta J$$
(5)

Also the motor constant may also change. Therefore,

$$K_t - K_{tn} - \Delta K_t$$
(6)

Then the disturbance torque $\tau_{dis}$ can be written as,

$$\tau_{dis} = \tau_l + \Delta J\ddot{\theta} - \Delta K_t I_a^{ref}$$
(7)

The dynamic equation can be written as,

$$(J_n + \Delta J)\ddot{\theta} = (K_{tn} + \Delta K_t) I_a^{ref} - \tau_l$$
(8)

After re arranging the terms of the above equation, following equation can be obtained.

$$J_n\ddot{\theta} = K_{tn}I_a^{ref} - \tau_{dis}$$
(9)

Therefore $\tau_{dis}$ can be calculated as,

$$\tau_{dis} = K_{tn}I_a^{ref} - J_n\ddot{\theta}$$
(10)

Above equation can be transferred in to a control diagram and is given below. This represents the motor equation with the disturbance torque.

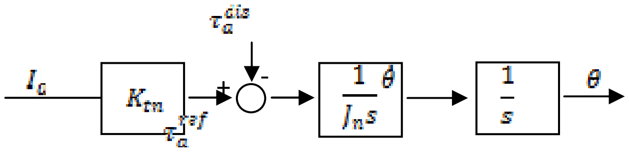



Fig. 1: Control diagram of the motor with the disturbance torque

Disturbance observer can either be used as an acceleration controller [4] or as a position controller [5].

Fig. 1 shows the control diagram of the disturbance observer method and it gives out the disturbance torque $\tau_{dis}$ [6].

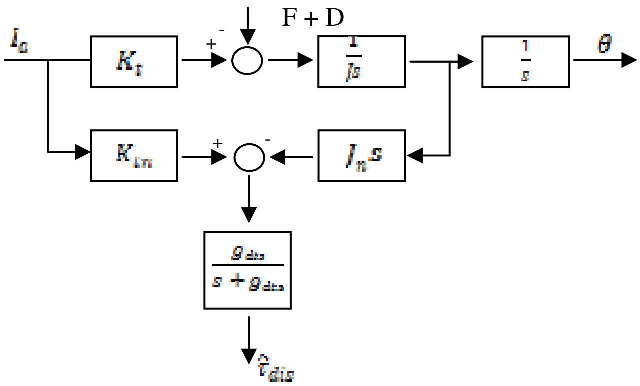



Fig. 2: Control Diagram of Disturbance Observer

Here,

$g_{dis}$ = Angular cut off frequency of the low pass filter

$\tau_{ext}$ = External Torques acting on the system

F + D$\dot{\theta}$ = Sum of coulomb and viscosity terms

$\hat{\tau}_{dis}$ = Disturbance torque

## 2. METHODOLOGY

For this research, a robot manipulator having two driving wheels is used. Two DC motors are attached to the wheels and both the motors can be controlled independently. Speeds of the wheels are measured using two shaft encoders attached to the wheels.

From the very beginning of this research, two assumptions are made to proceed with the further calculations.

1. Robot manipulator moves without slipping the wheels.
2. When the robot manipulator hits with an obstacle, it does not slip and will continue to move forward by pushing the obstacle.

When the mobile robot manipulator hits on a particular object when it is moving, this load torques acting upon the motors of the two wheels will get the additional torque exerted by the hitting of the object.

Suppose the robot manipulator hits with an obstacle as shown in Fig. 3. The point of hitting is chosen as arbitrary and is 'x' distance away from the left hand side wheel as shown in Fig. 4. The force exerted on the manipulator is F at the point of hitting.

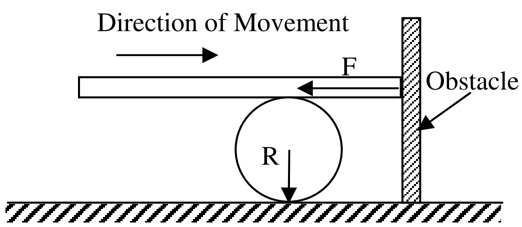



Fig. 3: Instance of hitting on the obstacle

This reaction force F can be divided in to two components acting along the two wheels as shown in Fig. 4.

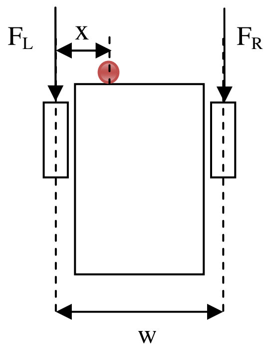



Fig. 4: Components of the Reaction Force

These $F_L$ and $F_R$ components can be found easily by taking the fractional components of F assuming that the width of the manipulator is 'w'.

$F_L - \frac{F(w-x)}{w}$ And $F_R = \frac{Fx}{w}$

(11)

These forces can again be decomposed in the plain perpendicular to the plain of $F_L$ and $F_R$ to convert it to the torques acting on the wheels. This is shown in the Fig. 5.

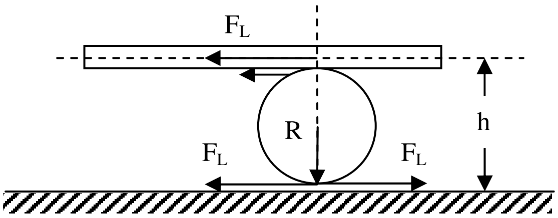



Fig. 5: Components of the $F_L$ in the perpendicular plane

$$\tau_L = (F_L.h - F_L.R) = F_L(h - R) \qquad (12)$$

Similarly,

$$\tau_R = (F_R.h - F_R.R) = F_R(h - R) \qquad (13)$$

By substituting from (11),

$$\tau_L = \frac{F(w-x)}{w}(h - R)$$

(14)

$$\tau_R = \frac{Fx}{w}(h - R) \qquad (15)$$

For the left hand side wheel,

$\tau_l$ F + D + (16)

Similarly the equation for the right hand side wheel can be obtained.

Thus $\tau_l$ for the right hand side wheel becomes,

$\tau_l$ F + D + (17)

Therefore the control diagram for one side of the robot manipulator can be drawn as below by modifying the control diagram of the disturbance observer.

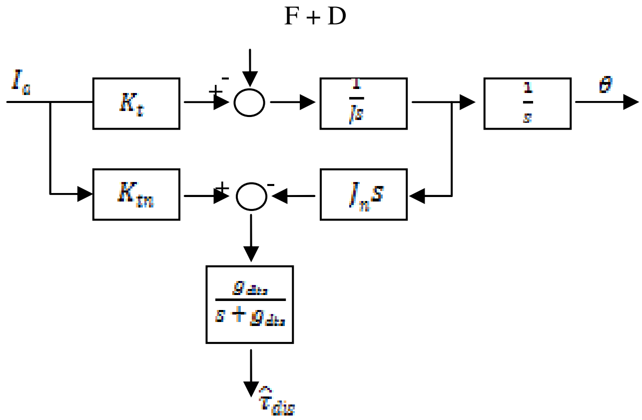



Fig. 6: Modified disturbance observer

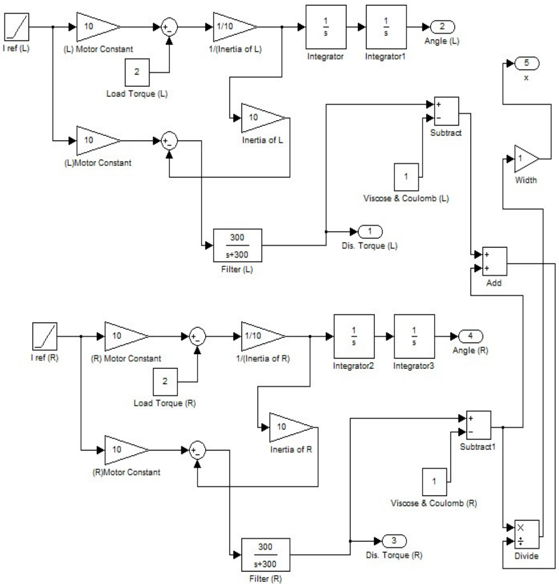
This control diagram is applied to the both of the wheels, so there are two of these. It is our goal is to find the distance 'x' at the end. From the equations obtained above, following equation can be derived.

$$\frac{\tau_L}{\tau_R} = \frac{(w-x)}{x} \qquad (18)$$

Re arranging this,

$$x = \frac{\tau_R w}{(\tau_L + \tau_R)} \qquad (19)$$

$\tau_L$ and $\tau_R$ can be obtained as the disturbance torques of the left and right hand side of the wheels. This can be included in to the complete control diagram




as illustrated in Fig. 7.

Two similar sets of blocks are in the diagram which corresponds to the left and right hand side of the wheels.

Fig. 7: Complete control block diagram

## 3. RESULTS

If the coulomb and viscosity terms are known, it is possible to calculate the $\tau_L$ and $\tau_R$ directly and get the distance 'x' as the output of the control diagram.

When the robot is in normal operation, the torques obtained from the feedback for both the wheels would correspond to the addition of inertial and external torques and coulomb and viscosity torques. But if the robot hits with an obstacle and continue to push it, the feedback torques differs from the previous torques.

Basically two instances can be found for hitting the robot with an obstacle and they are illustrated in Fig. 8 and Fig. 11. The obstacle is indicated in dark circle.

Scenario 1: When the robot is moving on a straight path

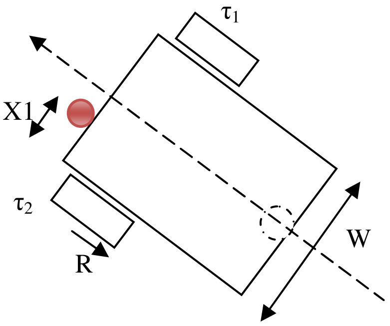



Fig. 8: When the robot is moving on a straight path

In this case the torques of the right and left hand side of the wheels are equal if the robot is running in its normal operation without pushing any obstacle as there's no any $\tau_L$ or $\tau_R$ terms for the load torque.

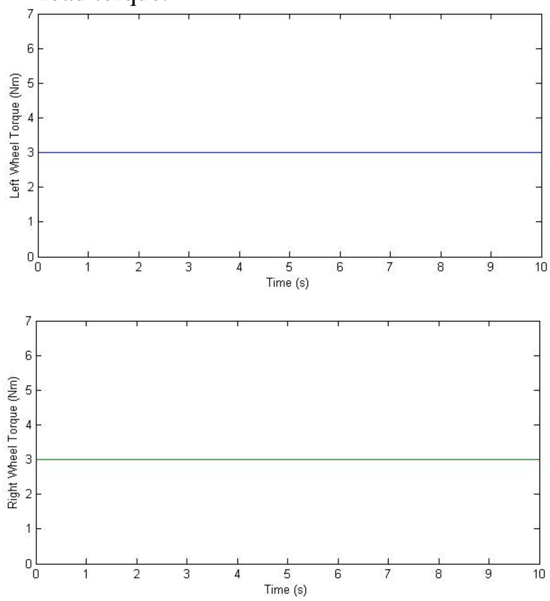



Fig. 9: Load torques of the two wheels when in normal operation.

When the robot manipulator hits with an object and keep on pushing it, the load torque will consist of the $\tau_L$ and $\tau_R$.

Suppose that the load torque profile is changing as in the Fig.10a and Fig.10b after the robot hits with the obstacle.

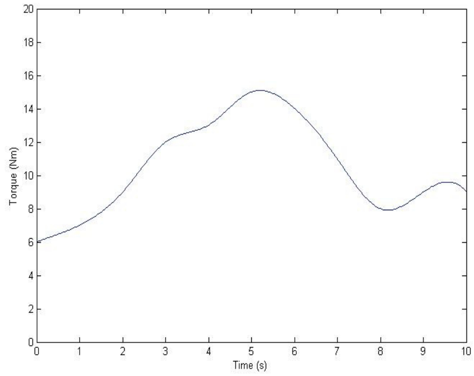



Fig. 10a: Load torque profile of the left wheel

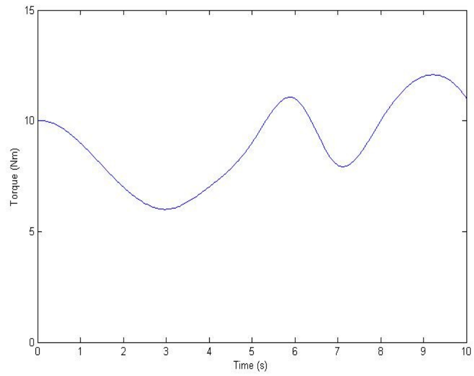



Fig. 10b: Load torque profile of the right wheel

When the load torques of the left and right hand side wheels change as above, the object will move along the bumper of the robot and the distance profile will be as in the Fig. 10c.

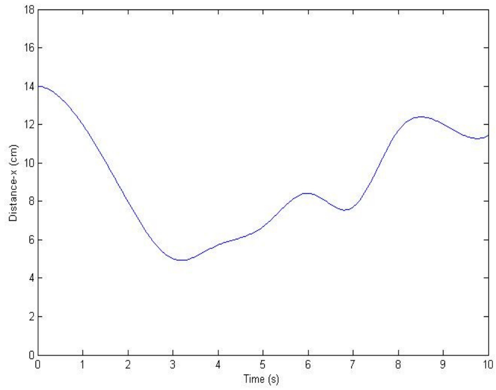



Fig. 10c: Change of the position of the object

Scenario 2: When the robot is moving on a curved path

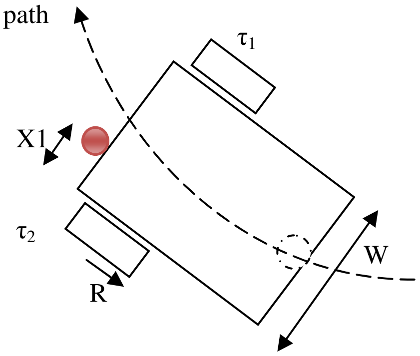



Fig. 11: When the robot is moving on a curved path

In this case, the torques of the two wheels are different even it is on normal move. Wheel towards the center of the curve will observe a higher torque compared to the wheel that is in the other side. With reference to Fig.11, $\tau_1$is greater than $\tau_2$ even the robot moves without striking the obstacle as illustrated.

Data for these diagrams have been taken for an instance when the robot manipulator moves on a circular path with a constant radius.

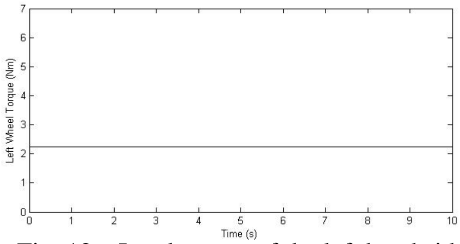



Fig. 12a: Load torque of the left hand side wheel

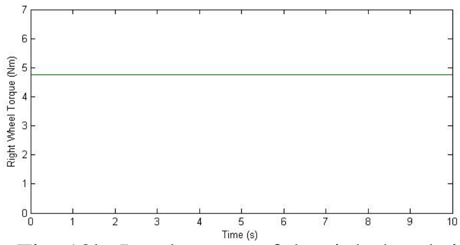



Fig. 12b: Load torque of the right hand side wheel

In this instance suppose the load torque profiles are changing as illustrated in Fig.13a and Fig.13b.

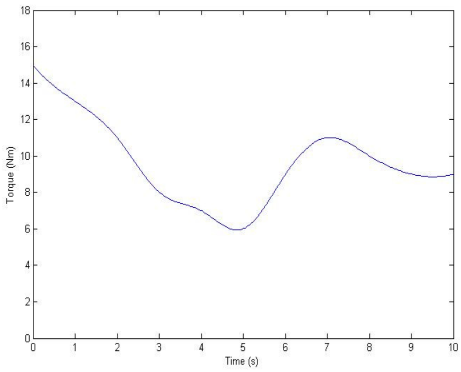



Fig. 13a: Load torque profile of the left wheel

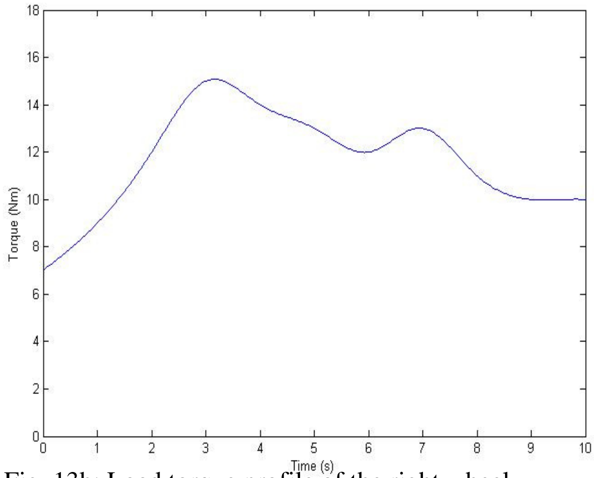



Fig. 13b: Load torque profile of the right wheel

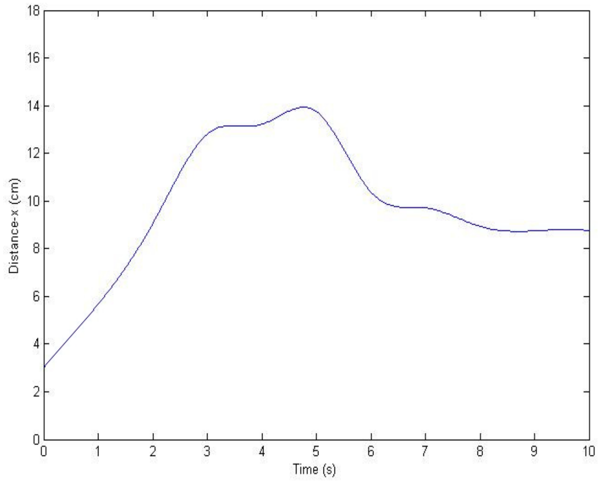



Fig. 13c: Change of the position of the obstacle

Fig.13c illustrates the change of distance ‘x’ with time corresponding to the load torque profiles given in Figure 13a and 13b.

When calculating the distance x for both the scenario 1 & 2, width of the robot manipulator ‘w’ was assumed to be 20cm. As the results for the scenario 2 have been obtained with an assumption, these results do not valid for curved paths having variable radii. In that cases Fig.12a and Fig.12b will have time varying load torques for both the wheels. In that situation, it is not possible to use the above control diagram directly. Subtrahend will also be time varying and hence will not be possible to just subtract in the case that is considered. Control diagram has to have some modification to get the instantaneous values of the load torques which is to be implemented together with an interface to put in between the reference current and the destination coordinates as described in the next chapter.

## 4. CONCLUSION

This method can be used to calculate the distance to the position of hitting from one edge of a robot manipulator. The only feedback that was taken here was the feedback from the shaft encoders. Under normal conditions number of micro switches has to be used as the tactile sensors to get this task done. But the problem with that is it is essential to use large number of tactile sensors. Even if that is done so, the resolution and the accuracy are low. But in this method a very good resolution and accuracy can be achieved for distance ‘x’ as the disturbance observer method gives very accurate results for the force feedback.

Feedback noise is negligible in this method which is a great advantage. If potentiometers with the springs are used as torque sensors, the sensitivity might not be enough to get precise values.

These results have been obtained by doing the simulation only. When it comes to the practical situations, various problems may arise. At the very beginning of the research, it was assumed that the robot manipulator does not slip when pushing the obstacle. Slip depends on the nature of the arena. Therefore there can be even slightest slip in some places of the arena although it is considered it to be having a rough floor. If that happens, these results will be false. There

This model is developed as taking the currents of the motors as the inputs. But in the practical situation, current cannot be given as the input but the coordinates of the destination. Therefore there should be some additional blocks that interface the destination coordinates and the input current. This research can be proceeded for further to implement that also.

Apart from this, another research can be done in parallel to this to calculate the weight of the obstacle. Reaction force exerted on the robot manipulator by the obstacle depends on the weight [7] of the obstacle also. Therefore the load torques of the two wheels also depends on that. Using the same model with some few modifications it is possible to obtain the weight of the obstacle. This will be very much useful in the instances where, it is required to measure the weight of an object when the lifting is not possible, provided that the friction coefficient (μ) of the surface is known.

This method can also be used to compare and analyze the behavior of a mobile robot manipulator under various operating conditions.

Considering all together it is clear that carrying out this research for further would be better to obtain the practical results as well, because it opens up paths to some other researches as well.

## 5. REFERENCES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