Simple discrete time traction control for a two-wheeled mobile robot

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Abstract. Traction controls usually need dynamic parameters as an approximated reference in the model, such as inertia and friction or heavily computational estimator, such as slip ratio estimator and friction estimator. This paper is shown that the dynamic parameters in the traction controller can be negligible in some cases, internal sensor state variables and gain parameters are enough to retain some traction controllability. The controller is derived from the model following control method (MFC) on a discrete domain. Experiments are performed, in order to evaluate the efficiency of the simplified controller using a two-wheeled mobile robot, by comparing slippage between the position and velocity control scheme with and without the traction control scheme. The experimental results show that the proposed traction control scheme is able to suppress the slip and very simple to implement.

1. Introduction
Nowadays, most commercialized mobile robots need to be robust, advanced, reliable, and simple with good maneuverability. Many researchers have been developed mobile robots to achieve these goals [1-3]. The applications are varied from rescuing to vacuums cleaning, from industrial to domestic. This project is to develop a mobile robot platform suitable for using in hospital as well as household for robot-assist evaluation, caring and rehabilitation services for the elderly and post-stroke patients. The maneuverability with good traction control of the robot will be based on two-wheeled is concentrated in this phase. Wheels on the robot are the most common form of maneuverability as the mechanism is straightforward with high dependability and still very popular for the new development of mobile robots such as the moon rover [4].

With the previous research on electrical vehicles, many sophisticated control algorithms were developed [5-10]. To extend the range of applications of the mobile robot, those advance control algorithms are needed to apply in the robotic field. Many traction control algorithms also have been developed in the past [5-6, 11]. This research explores the possibilities of the traction control algorithm.

To achieve the optimum travel speed with wheels on any plane, slip prevention must be realized. Without traction control algorithm, a wheel can be slip while driven with the torque which surpasses the friction force between wheels and floor. Moreover, retaining traction is important for driving in the desired direction otherwise the robot may turn unintentionally. Without additional orientation sensor, to maintain the driving direction, traction control is necessary. The traction control algorithm used in this research is developed based on the previous work, which used the model following control method (MFC) [11]. In this work, the simplification of the MFC is presented to show that dynamic parameters are negligible to some extends. The traction control is tested on the mobile robot and compared the result of the ones with position and velocity control.
In this paper, there are 6 main sections organized as follows: The description of the mobile robot used in this research is stated in section 2, including the wheel configuration and robot specification. Section 3 states the baseline control scheme, a kind of classic position and velocity control schemes. Section 4 states the importance of the traction, previous traction controller, and the derivation of the simple discrete time traction control. The experiment condition is stated in section 5. In section 6, the result of the experiments is shown and discussed. Then the conclusion and future works are in section 7.

2. The two-wheeled mobile robot

The two-wheeled mobile robot as shown in Figure 1 is driven by two brushless motors and planetary gears are used to reduce the speed by the gear ratio of 1:6, which form a differentially steered drive system. The driven wheels are made of aluminum with rubber tire and the 4 caster wheels are used as the passive support wheels. The robot is powered by two 12V VRLA batteries in series to obtain 24 voltages. The driven wheels always contact on the floor by a suspension mechanism made by springs. Table 1 shows the specifications of the robot.

The wheels’ motion will be controlled with a position and velocity controller and a traction controller. Trapezoidal velocity trajectory is used as a reference to attain the desired velocity and acceleration. To maintain the orientation of the robot, both wheels must maintain the same velocity at all time.

Table 1. The specifications of the two-wheeled mobile robot.

| Specifications            |   |
|--------------------------|---|
| Stall torque             | 78 Nm |
| Max. continuous torque   | 5.784 Nm |
| Maximum speed            | 1.38 ms⁻¹ |
| Maximum power            | 260 W  |
| Wheels diameter          | 200 mm |
| Encoder                  | 2500×4 pulse |
| Dimension                | 57×50×30 cm |
| Sampling rate            | 2000 Hz |

Figure 1. (a) The two-wheeled mobile robot, (b) the wheel
3. Position and velocity control scheme
To realize position and velocity tracking accuracy, the controller was designed without taking dynamics of the mobile robot into consideration. Each wheel is controlled separately. The position control is achieved by position feedback from the encoder on each wheel. The velocity feedback is calculated by the derivative of the wheel encoder position and the feedback signal is sent to achieve the velocity control. Each feedback signal has each own gain parameter multiplier, resulting in the whole feedback system work as a PD controller, which is ready for trajectory tracking control for both position and velocity as shown in Figure 2.

Reference position ($\theta_r$) and velocity ($\dot{\theta}_r$) are determined by the trajectory planner then the position ($\theta_m$) and velocity ($\dot{\theta}_m$) are fed back to perform closed-loop control with gain $K_p$ and $K_d$. The wheel velocity calculated by performing derivation and low pass filtered on the position signal.
So, the control law is

$$u = K_p(\theta_r - \theta_m) + K_d(\dot{\theta}_r - \dot{\theta}_m)$$

(1)

4. Traction control scheme
Many works have been done in the traction control algorithm, e.g. traction control with slip estimator for a rocker-bogie robot [12], traction control with dynamic tire friction model [13], optimal slip ratio control and model following control [11].

The model following control (MFC) is simple to implement as it does not need the implementation of the tire-floor friction estimator or slip ratio estimator. MFC has also been verified through experiments for simple traction control [14].

To prevent the slip phenomenon, the modified implementation of the MFC is utilized in this two-wheeled robot. The block diagram of MFC is shown in Figure 3.
The MFC prevent slip by reducing the output with the signal from a slip estimator. The output from the position and velocity controller \(T\) is used to estimate the wheel velocity and the slip is estimated by filtering the difference of the measured velocity and the estimated velocity. The time constant of the high pass filter \(\tau\), gain \(K_H\), and system inertia \(J\) need to be chosen for this model. If slip, the sudden change of the measured velocity will be detected, and the slip will be reduced by the controller.

The output from the block diagram is

\[
    u = \left[ T \left( s + \tau^{-1} \right) - K_H \dot{\theta}_m s \right] \left( s + \tau^{-1} - K_H J^{-1} \right)^{-1}
\]  

For implementation, the bilinear transformation was utilized. The bilinear transformation is a mathematical relationship which is used to convert the complex Laplace domain \((s\)-domain\) into \(z\)-domain. Using the substitution

\[
    s = \frac{2z - 1}{t + z + 1}
\]

Where \(t\) is the system sampling time and \(z\) is the complex function variable.

And then

\[
    u = \frac{T \left[ 2(z - 1) + \tau^{-1}t(z + 1) \right] - K_H \dot{\theta}_m 2(z - 1)}{2(z - 1) + \tau^{-1}t(z + 1) - t(z + 1)K_H J^{-1}}
\]

If the sampling time \(t\) is small enough, the part with \(t\) can be neglected

\[
    u = u z^{-1} + T \left( 1 - z^{-1} \right) - K_H \dot{\theta}_m \left( 1 - z^{-1} \right)
\]

with

\[
    T = K_p (\theta_r - \theta_m) + K_d (\dot{\theta}_r - \dot{\theta}_m)
\]

After the control law is simplified by removing the part with a very small coefficient, the high pass filter time constant and the system inertia are neglected, making the control law dynamically independent.

The output from the position and velocity controller \(T\) is used together with the wheel velocity signal \(\dot{\theta}_m\), calculated from the derivative of \(\theta_m\), to make a slip prevention controller. The gain \(K_H\) is chosen to achieve the traction force.

5. Experiments
To verify the traction control law, both controllers are tested under the same experimental environment and parameters. The trajectory used in the experiment was generated using Trapezoidal velocity trajectory planner. The maximum velocity and acceleration are 1.3 ms\(^{-1}\) and 1.5 ms\(^{-2}\) respectively.

The mobile wheels are made of rubber and the floor is made of polished stone. The trajectory of each wheel of the robot is generated with the same parameter, that is, same position, same velocity, and same acceleration at any point in time. Ideally, the robot will move straight if slips did not occur.

6. Results and discussion
Figure 4 shows the result form the position and velocity controller and the traction controller. Figure 5 shows the timeline of the motion of the robot. The robot moves from the starting position at \(t = 0\) sec
to the position of the stop at $t = 3\, \text{sec}$ (right to left). The robot in Figure 5a was driven with the position and velocity controller and the same robot in Figure 5b was driven by the traction controller. It is assumed that if both wheels exert the same amount of traction force, the robot will move straight. But if either of wheels slips, the force from each tire will be unbalanced and the robot will turn unintentionally.

(a) \hspace{2cm} (b)

Figure 4. The Trapezoidal velocity trajectory tracking by (a) the position and velocity controller, (b) the traction controller

(a) \hspace{2cm} (b)

Figure 5. The motion of the robot while driven with (a) the position and velocity controller, (b) the traction controller

(a) \hspace{2cm} (b)

Figure 6. The orientation of the robot with (a) the position and velocity controller, (b) the traction controller
In Figure 4a, the spike of the acceleration at the beginning shows that a wheel is slipped, corresponding with the robot in Figure 5a and Figure 6a. The slip causes the robot to turn and drive off the course. The slip also occurred at the end of the motion, generated by the deacceleration, which make the robot turn again but in the opposite direction.

The traction control law result was evaluated in Figure 4b. The velocity gradually increases without the spike in acceleration signal. The traction control was able to suppress the slip. From the robot motion in Figure 5b and the orientation in Figure 6b, the slip did not happen as the robot drive in a straight line and did not have any observable rotation motion.

The orientation of the robot shown in Figure 6 calculating from the yaw rate which measured with the 3DM-GX2 gyro sensor.

7. Conclusion and future work
The slip occurred in the first position and velocity controller experiment, noticeable from the spike of the acceleration at the beginning and the motion made by the robot and was managed to suppress by the modified MFC traction control law, which means the simplified MFC traction control works.

The MFC has proven effective on both EV and wheeled mobile robot but still required suitable dynamic parameters for implementation. Nevertheless, in the discrete domain, the MFC controller can be made simpler by the neglected some terms in the control law with sampling time multiplier. This approximation eliminates the dynamic parameter. The remaining terms in the control are related to state variables and gain parameter. With this simplification, the traction control is still successful according to the experimental results.

Future work will involve the estimation of the maximum traction force on any surface-pair using traction control on the wheeled mobile robot. Exploring other sophisticated traction controllers will be also considered.

8. References
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