Traction Control for Curling Robot Driving on Ice

Jung Hyun Choi, Young Hun Chung and Sehoon Oh[1,a)]

Abstract: This paper propose a velocity control for two-wheel driven mobile robot driving on the ice. The traction control requirements for a driving on the ice is obtained from driving scenario of the robot. The important requirements of the robot are to satisfy the target velocity in the given distance. To achieve the given velocity of the robot on the ice, longitudinal velocity control is adopted, and Model Following Control method is adopted to prevent slip phenomenon on the ice. Validity of the suggested control algorithms is verified by experimental results.

1. Introduction

Recently, robot technologies are used to various application entertainment as well as industrial field. Demand for wheel based mobile robot also has been increased as method to give mobility in their applications. Various kinds of mobile robots also have been developed and successfully commercialized as the wheels are the most dependable and practical mechanism for the robot locomotion. Ever since robot vacuums have opened the way for the mobile robots to be utilized for the indoor service, there have been many mobile robots developed for various services including the most popular robot, Pepper [1].

While these mobile platforms have been researched and commercialized, the algorithms investigated for the mobile robots are usually limited to kinematic control [2] and navigation. On the other hand, lots of advanced dynamic driving control algorithms were developed for electric vehicle and electric wheelchairs [3].

The mobile robots now may not benefit from these advanced control algorithms, but they will need the control algorithms when the application fields of the mobile robots are extended to more severe cases, such as very cold or sloppy terrains.

To perform stone throwing task as given from user command(In this study, the user is Artificial Intelligence(AI) system)on the ice field, the precise motion control such as longitudinal velocity and heading angle is required to the curling robot.

In this study, a curling robot that is developed to perform curling game is introduced and the traction control algorithm including anti slip and velocity control is proposed.

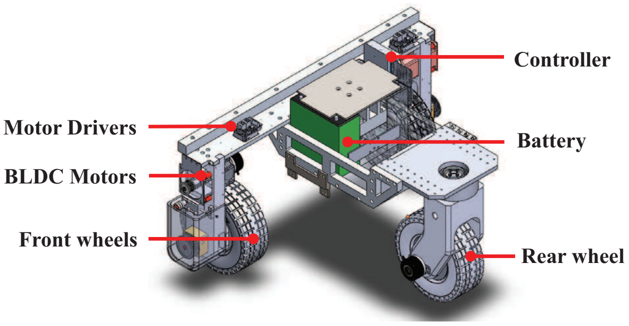
2. Recommendation

Figure 1(a) shows that 3D CAD of two-wheel driven curling robot that is designed to perform tasks on the ice. The robot has two active wheels and one passive wheel. Two active wheels are connected to two BLDC motors through timing belts and reduction gears and one passive wheel is a caster. Both front and rear wheels adopt solid rubber tires with grooves on the surface to obtain higher friction than the flat-shaped ones. The slip between the tire and the ice is a significant issue in the curling robot driving, particularly when it is driven at high speeds. When the curling robot is required to reach high speeds quickly, high acceleration is necessary which is the case for the proposed curling robot. Note that the rear wheel consists of a caster which does not have any active steering motor, which means that the orientation of the mobile robot is affected only by the difference between the torques of two driving wheels. Namely, both the longitudinal directional motion and rotational directional motion are controlled by two motors of the driving wheels, as illustrated in Fig. 2.

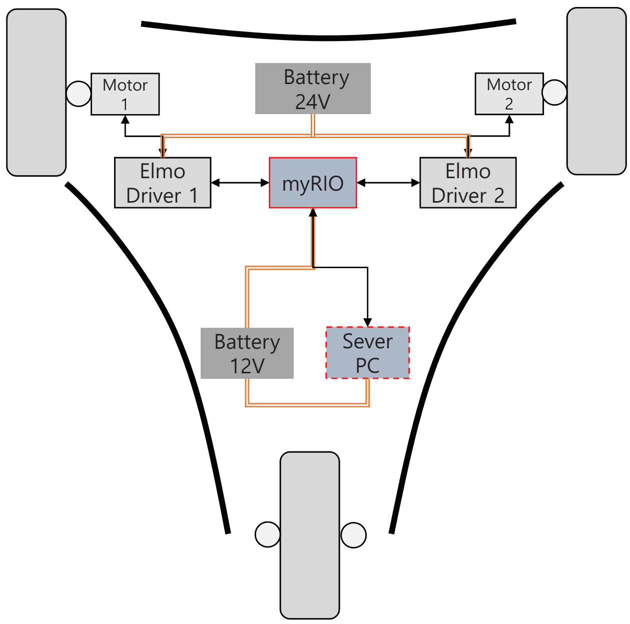
Figure 1(b) shows the schematics of the electric structure of the robot: main controller for the robot control is implemented in myRIO real-time OS embedded system (National Instruments). The sampling time of the controller was set to $1ms$ to execute high precision and speed control. ELMO motor drivers are employed for the current control of BLDC motors, the reference which is delivered from the myRIO via analogue voltage signals. All of the power source of electrical devices is supplied from a Li-Ion battery package. The detailed specification of the robot is indicated in Table 1.

The mobile robot needs a proper control algorithm to meet the requirements that is anti slip control, achieve target velocity and keeping constant heading angle. Figure 3 shows overall control algorithm for the given task on the ice. To prevent slip between the tire and the road, anti slip controller(Model Following Control [4]) is applied to each motor as inner-most control loop. Note that this MFC is a simple and rough approach to prevent slip, which shows a limited performance of re-adhesion, and there are many other more effective anti slip control such as Slip Ratio Estimation/Control(SRE,SRC) [5], Direct Driving Force Con-

[1] DGIST, Department of Robotics Engineering, Daegu, 42988, Korea
[a)] sehoon@dgist.ac.kr



(a) Mobile robot prototype



(b) Electronic structure of the mobile robot

Fig. 1 Mobile robot driving on ice

Table 1 Mobile robot specification

Parameter	Value
Total weight	73 kg
Wheel Radius	0.125 m
Wheel Inertia	0.03 kgm^2
Max. Motor Torque	0.99 N/m
Shaft Encoder	10,000 Pulse/turn

trol(DDFC) [6] and Driving Force Control(DFC) [7]. However, in this study, since the road condition which is the friction coefficient between tire and road can be assumed (almost) to be constant. Thus, MFC approach is considered to be sufficient for this anti slip control.

Figure 4 shows the proposed longitudinal velocity controller for the robot to track the generated velocity trajectory, which consists of feedback controller (FB) and feedforward controller (FF). Controller design for FB control and FF control are given as (1) and (2) respectively.

$$C_{FB} = K_p + K_d s \tag{1}$$

$$C_{FF} = \frac{J_n s + B_n}{\tau s + 1} \tag{2}$$

In this paper, FB and FF controller were adopted to reduce steady state error, and no integral (I) controller is employed to avoid stability problem. It is well known that FF

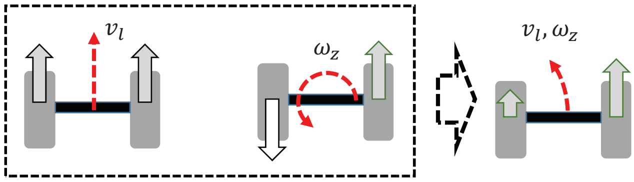


Fig. 2 Driving method on two-wheel driven mobile robot

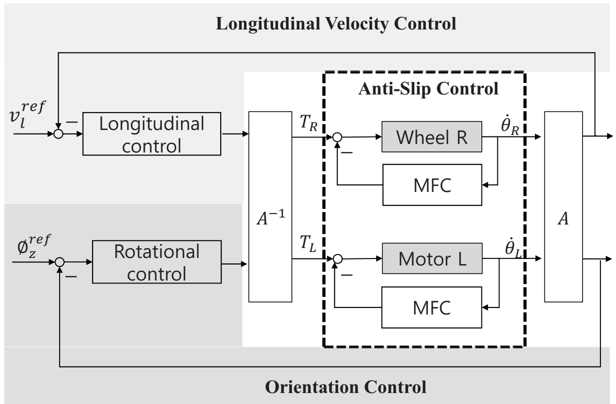


Fig. 3 Whole control algorithm of the mobile robot

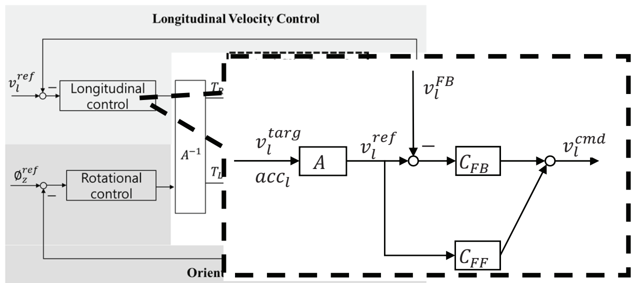


Fig. 4 Longitudinal velocity with feedback and feedforward controller

controller with proper gains can be utilized to reduce steady state error.

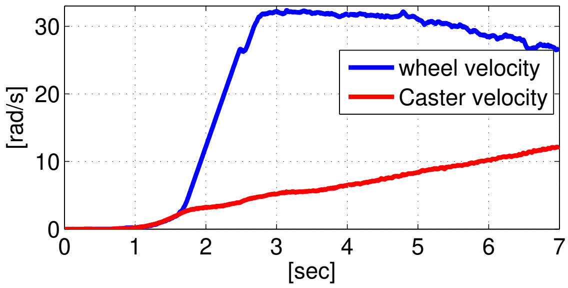
3. Promising results

As soon as slip occurs, traction force of the robot decreases rapidly, and the robot loses acceleration as well as driving stability. When the wheel torque is larger than the adhesion force from the friction force between tire and road, the slip can happen. To successfully obtain the desired velocity of the curling robot, no slip between the tire and the ice is allowed for the robot.

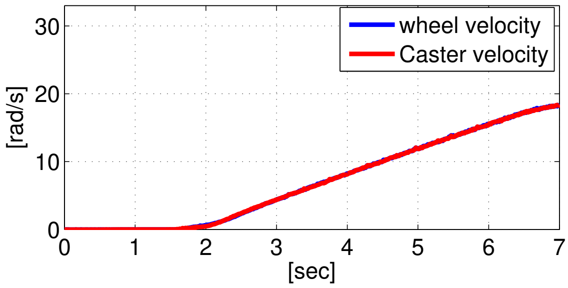
To verify the performance of MFC, the adopted anti slip control, a constant current command up to $8A$ was given to obtain large acceleration of the robot. Figure 5 shows the result of the wheel velocity with and without MFC, where MFC gain and cut-off frequency is set to 1.6, 2.1 Hz respectively.

The red line in Fig. 5 indicates the wheel velocity of the driving wheel and the blue line indicate the robot velocity which was measured by the encoder attached on the non-driving wheel. Without MFC, slip phenomenon occurs around from 1.7 second in the Fig. 5(a).

On the other hand, there is no slip between the tire and

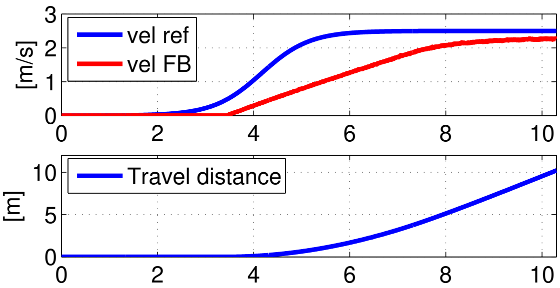


(a) Without MFC

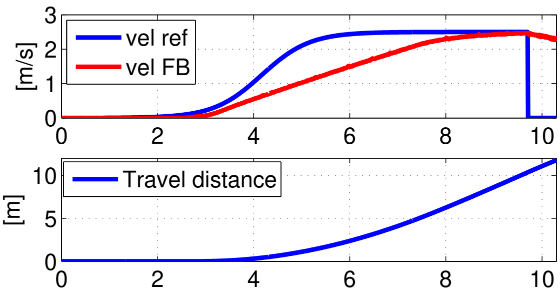


(b) With MFC

Fig. 5 Experimental results of MFC



(a) Longitudinal velocity with only feedback controller



(b) Longitudinal velocity with feedback and feedforward controller

Fig. 6 Experimental results of longitudinal velocity

the ice with MFC, showing that both wheel velocity and robot velocity are almost same as shown in Fig. 5(b).

As described in previous section, the target velocity is given to the robot, and the robot needs to reach the target velocity at a certain point precisely. A proper velocity trajectory generation and tracking control are essential for this task. Note that the torque and the distance for the robot to proceed are limited. To this end, the sigmoid function is used for velocity trajectory in this research, as depicted in (3).

$$V_{ref}(t) = \frac{A}{1+\exp^{(-Bt+C)}}, \tag{3}$$

where, A means the target velocity, B means starting time of the trajectory, and C means the acceleration value of the trajectory. The velocity trajectory was designed based on (3), and the tracking performance was verified with only FB control and with both FB, FF control. In this experiment, the target velocity was set to 2.5 m/s. The velocity trajectory in Fig. 6(a) and Fig. 6 (b) were set to have the same sigmoid parameters as $A = 2.5$, $B = 2$, $C = 11$ in (3).

With only FB control, where Proportional-Derivative (PD) controller as expressed in (1) was used with $K_p = 17$, $K_d = 0.001$, there is large velocity error when robot passes the goal distance(10 m) as shown in Fig. 6 (a). In the case of FB and FF control, the error dramatically decreases as shown in Fig. 6 (b); the robot reaches at the target velocity before crossing 10m movement. The same PD gains were used in this control, and the first order nominal model was utilized for FF control as (2) with the nominal inertia $J_n = 0.22$, nominal damping $B_n = 0.095$ and 0.5 Hz of the cut-off frequency.

4. Conclusion

In this study, anti slip control and longitudinal velocity control were proposed for the curling robot driving on the ice. MFC controller was verified to suppress slip phenomenon on the ice driving. Longitudinal velocity tracking control is also proposed with feedback and feedforward controller. The performance of the proposed longitudinal velocity tracking control was verified through experiments.

Acknowledgment

This work was supported by Institute for Information and communications Technology Promotion(IITP) grant funded by the Korea government(MSIT)(No.2017-0-00521, AI curling robot which can establish game strategies and perform games).

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