Predictor-based Tracking Control of
A Mobile Robot with Time-delays

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Abstract: In this paper, we consider the tracking control problem for a two-wheel mobile robot which has a feedback loop that passes through a computer network. The use of a computer network in the feedback loop causes several problems, but we focus particularly on the effect of time-delays caused by the data transmission. To compensate the performance degradation due to the delays, we propose a tracking control scheme with a state predictor based on anticipating synchronization. A sufficient condition for the convergence of the prediction error is also derived by the Lyapunov-Razumikhin approach. Numerical simulation results show that the proposed control scheme is effective for driftless non-holonomic systems such as the mobile robot.

Keywords: state prediction, synchronization, time-delays, non-holonomic systems, mobile robot

1. INTRODUCTION

In recent years, the study of synchronization phenomena in nonlinear systems has made a number of significant advances in interdisciplinary fields such as applied physics, life sciences, mathematical biology and control theory. Nowadays, the interest is spreading to expression of synchronization in coupled systems with time-delay (e.g. Oguchi et al. (2008, 2009)). Unlike other fields which have concentrated on analysis of the phenomena, researchers in the field of control theory have given interest to not only analysis of synchronization phenomena but also systematic generation of the phenomena from viewpoint of control design (Nijmeijer and Mareels (1997)). In particular, observers in control theory can be regarded as a kind of the master-slave synchronization, and it can be also considered as a typical example of practical application of synchronization. On the other hand, it is well-known that an interesting behavior called anticipating synchronization can be observed for coupled chaotic systems with time-delay. The occurrence of the anticipating synchronization was firstly discovered for chaotic systems with time-delay in a unidirectional coupling configuration by physicist Voss (2000). This phenomena has been investigated as an extension of chaos synchronization from a viewpoint of physical science and can be observed for physical systems (Masoller (2001); Voss (2002); Sivaprakasam et al. (2001)). After that, Oguchi and Nijmeijer (2005b, 2006) and Huijberts et al. (2007) considered anticipating synchronization in more general systems and showed sufficient conditions for anticipating synchronization to occur. Furthermore, since this phenomenon can be recognized as a state prediction method, Oguchi and Nijmeijer (2005a) proposed a control scheme for a class of nonlinear systems with time-delay by using anticipating synchronization as a state predictor.

In this paper, we attempt to extend this prediction control scheme for a non-holonomic system with input delay and saturation. Specifically, we address the tracking control problem for a two-wheel mobile robot in the configuration of networked control systems (NCSs) and focus on the effect of time-delays that arise in the system as a result of the use of communication networks. The existence of network-induced delays degrades the performance of the control system and tends to destabilize the whole system, but we show that the proposed control scheme can compensate the negative effect. In addition, we derive a sufficient condition for the convergence of the prediction error by using the Lyapunov-Razumikhin theorem. Numerical simulations illustrate the effectiveness of the proposed scheme and the derived condition.

2. PRELIMINARIES

This section describes the kinematics of a two-wheel mobile robot and the tracking control problem to be used later.

2.1 A two-wheel mobile robot

We consider a vehicle robot with two wheels rolling without slipping on the horizontal plane shown in Fig. 1. We
denote by \((x(t), y(t))\) the coordinates of point \(P\), which is the middle point of the axle and denotes the position of the mobile robot, \(\theta(t)\) the angle between the heading of the robot and the \(X\)-axis, and \(B\) the length of the wheel based. In addition, \(v_1(t)\) and \(v_2(t)\) denote circular velocities of the two driving wheels and these are the inputs of the mobile robot. Then, the kinematics of the mobile robot can be described by
\[
\begin{bmatrix}
\dot{x}(t) \\
\dot{y}(t) \\
\dot{\theta}(t)
\end{bmatrix} = \frac{1}{2} \begin{bmatrix}
\cos \theta(t) & \cos \theta(t) & \frac{v_1(t)}{2} \\
\sin \theta(t) & \sin \theta(t) & \frac{v_2(t)}{2}
\end{bmatrix},
\]
where \(v\) denotes the forward velocity and \(\omega\) the steering velocity, and the following relationships hold.
\[
v = \frac{v_1 + v_2}{2}, \quad \omega = \frac{v_2 - v_1}{2B}.
\]
Here, note that the velocities \(v\) and \(\omega\) are taken as the inputs and are subject to the following constraints due to saturation of motor input amplifier:
\[
|v(t)| < \bar{v}, \quad |\omega(t)| < \bar{\omega} \quad \forall t \geq 0
\]
where \(\bar{v}\) and \(\bar{\omega}\) are given positive constants.

Applying the equation (2) into the equation (1), we obtain
\[
\begin{align*}
\dot{x}(t) &= v(t) \cos \theta(t) \\
\dot{y}(t) &= v(t) \sin \theta(t) \\
\dot{\theta}(t) &= \omega(t).
\end{align*}
\]
Please note that the no-slip condition on the wheels imposes that the system has a non-holonomic constraint described by
\[
\dot{x}(t) \sin \theta(t) - \dot{y}(t) \cos \theta(t) = 0.
\]

2.2 Tracking control problem

Before considering the tracking control problem for the above mentioned mobile robot with time-delay and saturation at the inputs, we review a case of no time-delay. The objective here is to design a controller such that the robot tracks the desired trajectory \((x_d(t), y_d(t), \theta_d(t))\) generated by
\[
\begin{align*}
\dot{x}(t) &= v_d(t) \cos \theta_d(t) \\
\dot{y}(t) &= v_d(t) \sin \theta_d(t) \\
\dot{\theta}(t) &= \omega_d(t),
\end{align*}
\]
where \(v_d\) and \(\omega_d\) are continuous functions and denote the reference velocities defined by
\[
v_d(t) = \sqrt{\dot{x}_d^2 + \dot{y}_d^2}, \quad \omega_d(t) = \frac{\dot{x}_d \dot{y}_d - \dot{x}_d \dot{y}_d}{\dot{x}_d^2 + \dot{y}_d^2}.
\]

Adapting the error configuration approach proposed by Kanayama et al. (1990), the difference between the reference configuration \((x_d(t), y_d(t), \theta_d(t))\)^T given by (5) and the current configuration \((x(t), y(t), \theta(t))\)^T, which is the current position of the robot at the moment, defines the error coordinates \((x_e(t), y_e(t), \theta_e(t))\)^T described by
\[
\begin{bmatrix}
x_e(t) \\
y_e(t) \\
\theta_e(t)
\end{bmatrix} = \begin{bmatrix}
\cos \theta(t) & \sin \theta(t) & 0 \\
-\sin \theta(t) & \cos \theta(t) & 0
\end{bmatrix} \begin{bmatrix}
x_d(t) - x(t) \\
y_d(t) - y(t)
\end{bmatrix}.
\]
(6)

The relationship among these coordinates is depicted in Fig. 2.

Differentiating equation (6) with respect to \(t\) yields the following error dynamics.
\[
\begin{bmatrix}
x_e(t) \\
y_e(t) \\
\theta_e(t)
\end{bmatrix} = \begin{bmatrix}
\omega(t)x_e(t) + v_d(t) \cos \theta_e(t) \\
-\omega(t)x_e(t) + v_d(t) \sin \theta_e(t) \\
\omega(t) \theta_e(t)
\end{bmatrix}.
\]
(7)

This means that the asymptotic tracking of the given reference trajectory can be achieved by constructing the inputs \(v\) and \(\omega\) that asymptotically stabilize the origin of equation (7).

A control strategy for the tracking problem under the input-saturation requirement (3) is proposed by Jiang et al. (2001), and the proposed controller is given by
\[
\begin{bmatrix}
\omega(t) \\
v(t)
\end{bmatrix} = \begin{bmatrix}
\lambda_1 v_d(t) y_d(t) & \sin \theta_d(t) \\
1 + x_e^2(t) + y_e^2(t) & \theta_d(t)
\end{bmatrix} + h_{\lambda_3}(x_e(t))
\]
(8)
where \(\lambda_i\) for \(i = 1, 2, 3\) are positive design parameters, and \(h_{\lambda_3} \in \mathcal{F}_{\lambda_3}\) are in sets like
\[
\mathcal{F}_{\lambda_3} = \{ \phi : \mathbb{R} \to \mathbb{R} \mid \phi \text{ is continuous} \}
\]
\[
-\lambda_i \leq \phi(x) \leq \lambda_i \quad \forall x \in \mathbb{R},
\]
\[
\text{and } \phi(x) > 0 \text{ for all } x \neq 0\}.
\]

Applying the above feedback, the system (4) can achieve the asymptotic tracking under the input-saturation (3).

2.3 Lyapunov-Razumikhin theorem

Before closing this preliminary section, we briefly review a stability criterion for time-delay systems, which will be used later.

Now we consider the stability of the following retarded functional differential equation:
\[
\dot{x}(t) = f(t, x_t)
\]
(9)
where \(x(t) \in \mathbb{R}^n\), \(x_t = x(t+\theta)\) for \(\theta \in [-r, 0]\) and \(f : \mathbb{R} \times \mathcal{C}([-r, 0], \mathbb{R}^n) \to \mathbb{R}^n\). For the system, the Lyapunov-Razumikhin theorem is stated as follows.

Theorem 1. (Hale and Verduyn Lunel (1993)) Suppose \(f\) in (9) takes \(\mathbb{R} \times \text{(bounded sets of } \mathcal{C}([-r, 0], \mathbb{R}^n\text{)}) \to \mathbb{R}^n\) into...
bounded sets of \( \mathbb{R}^n \), and \( u, v, w : \mathbb{R}_+ \rightarrow \mathbb{R}_+ \) are continuous nondecreasing functions, \( u(s) \) and \( v(s) \) are positive for \( s > 0 \), and \( u(0) = v(0) = 0 \), \( v \) strictly increasing. If there exists a continuously differentiable function \( V : \mathbb{R} \times \mathbb{R}^n \rightarrow \mathbb{R} \) and a continuous nondecreasing function \( p(s) > s \) for \( s > 0 \) such that

\[
\dot{V}(t, \phi(0)) \leq -w(|\phi(0)|)
\]  

if

\[
V(t + \theta, \phi(\theta)) \leq p(V(t, \phi(0)))
\]  

for \( \theta \in [-r, 0], \) then the solution \( x = 0 \) of the system (9) is uniformly asymptotically stable. If \( u(s) \rightarrow \infty \) as \( s \rightarrow \infty \), then the solution \( x = 0 \) is also a global attractor for the system (9).

3. PREDICTOR-BASED CONTROL OF A MOBILE ROBOT WITH DELAYS

The objective of this study is to extend the above mentioned tracking control method of a two-wheel mobile robot for the networked control systems (NCSs) framework, in which a mobile robot and the corresponding tracking controller exchange the feedback signals and the control inputs through asynchronous communication network as shown in Fig. 3. In this section, we show that the predictor-based control method is applicable to control of a two-wheel mobile robot which is a driftless control system and has an non-holonomic constraint.

Fig. 3. Networked Control System of a mobile robot

Now we consider the above mentioned two-wheel mobile robot with time-delays at the inputs and the feedback signals as shown in Fig. 3.

\[
\begin{align*}
\dot{x}(t) &= v(t - L_1) \cos \theta(t) \\
\dot{y}(t) &= v(t - L_1) \sin \theta(t) \\
\dot{\theta}(t) &= \omega(t - L_1)
\end{align*}
\]  

Therefore this system can be rewritten as

\[
\begin{align*}
\dot{x}_p(t) &= v(t - L) \cos \theta_p(t) \\
\dot{y}_p(t) &= v(t - L) \sin \theta_p(t) \\
\dot{\theta}_p(t) &= \omega(t - L)
\end{align*}
\]  

where \( L = L_1 + L_2 \).

For this system, a controller based on the state prediction control consists of two parts: (a) a state predictor (b) a tracking controller. Each part is designed as follows:

(a) **State predictor:**

\[
\begin{bmatrix}
\dot{x}(t) \\
\dot{y}(t) \\
\dot{\theta}(t)
\end{bmatrix} = \begin{bmatrix}
v(t) \cos \theta(t) \\
v(t) \sin \theta(t) \\
\omega(t)
\end{bmatrix} - K \begin{bmatrix}
\dot{x}(t - L) - x_p(t) \\
\dot{y}(t - L) - y_p(t) \\
\dot{\theta}(t - L) - \theta_p(t)
\end{bmatrix}
\]  

(b) **Tracking controller:**

\[
\begin{align*}
\omega(t) &= \omega_d(t) + \frac{\lambda_1 v_d(t) y_d(t)}{1 + x_d^2(t) + y_d^2(t)} \sin \theta_d(t) \\
& \quad + h_\lambda(\theta(t)) \\
\dot{v}(t) &= v_d(t) \cos \theta_d(t) + h_\lambda(x_d(t))
\end{align*}
\]

where

\[
\begin{bmatrix}
x_d(t) \\
y_d(t) \\
\theta_d(t)
\end{bmatrix} = \begin{bmatrix}
\cos \theta(t) & \sin \theta(t) & 0 \\
-\sin \theta(t) & \cos \theta(t) & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
x(t - L) - x_p(t) \\
y(t - L) - y_p(t) \\
\theta(t - L) - \theta_p(t)
\end{bmatrix}
\]

Fig. 4 shows a configuration of the proposed tracking control system for the mobile robot with time-delayed inputs. In this control scheme, if the prediction error defined by

\[
e(t) := e_x(t) e_y(t) e_{\theta}(t)
\]

converges to zero, then \( (\dot{x}(t), \dot{y}(t), \dot{\theta}(t))^T \) can estimate the future value of the robot’s configuration. Therefore the convergence of the error to zero is crucial for the proper functioning of this control scheme.

Here we consider conditions for the convergence of the error to zero. The dynamics of the prediction error can be given by

\[
\begin{bmatrix}
e_x(t) \\
e_y(t) \\
e_{\theta}(t)
\end{bmatrix} = \begin{bmatrix}
\cos(\omega_d(t) + \theta_d(t)) - \cos \theta_p(t) & 0 & 0 \\
\sin(\omega_d(t) + \theta_d(t)) - \sin \theta_p(t) & 0 & 0 \\
0 & 0 & 0
\end{bmatrix} \begin{bmatrix}
v(t - L) \\
\omega(t - L)
\end{bmatrix}
\]

\[
- K \begin{bmatrix}
e_x(t - L) \\
e_y(t - L) \\
e_{\theta}(t - L)
\end{bmatrix}
\]

\[
= A_1 e(t) A_2 e(t - L) - K e(t - L)
\]

where

\[
A_1 = \begin{bmatrix}
\cos(\omega_d(t) + \theta_d(t)) - \cos \theta_p(t) & 0 & 0 \\
\sin(\omega_d(t) + \theta_d(t)) - \sin \theta_p(t) & 0 & 0 \\
0 & 0 & 0
\end{bmatrix}, \quad A_2 = \begin{bmatrix} A_1 \end{bmatrix}
\]

and the \( e \equiv 0 \) is a trivial solution of the difference-differential equation (18). Here we derive a sufficient condition for the origin of eq. (18) to be asymptotically stable.

**Theorem 2.** Consider system (14) and the corresponding state predictor (15). Then, the prediction error \( e(t) \) asymptotically converges to zero if there exist positive gains \( k_1, k_2 \) and \( k_3 \) satisfying the following inequalities:

\[
\begin{align*}
(1) & \quad k_1 \dot{v} + 2k_2 \dot{\theta} \leq -\ddot{v} + 2k_1 \\
(2) & \quad k_2 \dot{v} + 2k_3 \dot{\theta} \leq -\ddot{v} + 2k_2 \\
(3) & \quad \{(k_1 + k_2)^2 \dot{v} + k_3 \} \leq -2 \ddot{v} + k_3
\end{align*}
\]

where \( L \geq 0 \) denotes a constant time-delay.

**Proof.** By applying the Lyapunov-Razumikhin theorem, let us show that the origin of the prediction error dynamics (18) is asymptotically stable. Applying Leibnitz’s law

\[
e_i(t - L) = e_i(t) - \int_{t-L}^{t} e_i(s)ds, \quad i = \{x, y, \theta\},
\]

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the system (18) can be transformed to the following
distributed delay system
\[
\dot{e}(t) = -K e(t) - K_2 \int_{t-L}^{t} e(s-L)ds
+ KA \int_{t-L}^{t} v(s-L)ds + Av(t-L).
\] (22)

Let us consider the following Lyapunov function candidate
\[
V(e(t)) = e^T(t) \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1/2 \end{bmatrix} e(t).
\]

Paying attention to the fact that the third equation of the
system (22) is independent of \(e_x\) and \(e_y\), we consider the
stability of the third equation first. Let \(V_2(e_0(t)) = \frac{1}{2}e_0^2(t)\), then the derivative of \(V_2\) along (22) is given by
\[
\dot{V}_2(e_0(t)) = e_0(t) \left\{ -k_3 e_0(t) - k_2^2 \int_{t-L}^{t} e_0(s-L)ds \right\}.
\]

Assuming the Razumikhin condition (12), i.e. if there
exists a \(q > 1\) satisfying \(V_2(e_0(t) + \eta)) \leq q V_2(e_0(t))\) for all
\(-2L \leq \eta \leq 0\), we obtain
\[
\dot{V}_2(e_0(t)) \leq -k_3 e_0^2(t) + k_3^2 \int_{t-L}^{t} |e_0(s-L)|ds
\]
\[
\leq -k_3 e_0^2(t) + k_3^2 |e_0(t)| \int_{t-L}^{t} q |e_0(s)|ds
\]
\[
= -k_3 (1 - k_3qL)|e_0(t)|^2.
\] (23)

Next, we consider the dynamics of \(e_x\) and \(e_y\).

Defining \(e_{xy} = (e_x(t), e_y(t))^T\) and \(K_1 = \text{diag}(k_1, k_2)\), we set
\[
V_1(e_{xy}(t)) = e_{xy}^T(t)e_{xy}(t).
\] (24)

The derivative of (24) along (22) is
\[
\dot{V}_1(e_{xy}(t)) = 2 e_{xy}^T(t)e_{xy}(t)
\]
\[
= 2e_{xy}^T(t) \left\{ -K_1 e_{xy}(t) - K_1^2 \int_{t-L}^{t} e_{xy}(s-L)ds
\right.
\]
\[
+ K_1 A_1 \int_{t-L}^{t} v(s-L)ds + A_1 v(t-L) \right\}
\] (25)

Using the relation \(V_1(e_{xy}(t) + \eta)) \leq q V_1(e_{xy}(t))\) for all
\(-2L \leq \eta \leq 0\) and \(q > 1\), and substituting the inequalities
\[
|\sin(e_{xy}(t) + \theta(t)) - \sin \theta(t)| \leq |e_{xy}(t)|
\]
\[
|\cos(e_{xy}(t) + \theta(t)) - \cos \theta(t)| \leq |e_{xy}(t)|
\]
\[
||e_{xy}(t)|| \leq |e_x(t)| + |e_y(t)|
\]
to (25), we obtain
\[
\dot{V}_1(e_{xy}(t)) \leq -2e_{xy}^T(t) K_1 e_{xy}(t)
\]
\[
- 2e_{xy}^T(t) K_1^2 \int_{t-L}^{t} e_{xy}(s-L)ds
\]
\[
+ 2|e_{xy}^T(t) K_1 A_1| \int_{t-L}^{t} vds + 2|e_{xy}^T(t) A_1| |v|
\]
\[
\leq -2e_{xy}^T(t) K_1 e_{xy}(t) + 2qL e_{xy}^T(t) K_1^2 e_{xy}(t)
\]
\[
+ 2L||e_{xy}(t)|| K_1 |e_{xy}(t)||v| + 2|e_{xy}(t)||e_{xy}(t)||v|
\]
\[
\leq -2k_1(1 - k_1qL)||e_{xy}(t)||^2 - 2k_2(1 - k_2qL)||e_{xy}(t)||^2
\]
\[
+ 2v(1 + k_1qL)||e_{xy}(t)||e_{xy}(t)||v|
\]
\[
+ 2v(1 + k_2qL)||e_{xy}(t)||e_{xy}(t)||v|
\] (26)

 Remark 1. Theorem 2 guarantees that for any given
initial condition of the predictor, the prediction error
asymptotically converges to zero. However, note that this
does not imply the stability of the total system because the
separation principle does not hold for nonlinear systems.

4. NUMERICAL EXAMPLES

In this section, we demonstrate the effectiveness of the
proposed control scheme and the appropriateness of the
condition derived in the foregoing section by numerical
simulations. As a practical situation, we consider to apply
this predictor based control method into a remote tracking
control of an E-puck mini mobile robot (Mondada et al.
(2009)), which has been originally developed by the Swiss
Federal Institute of Technology in Lausanne (EPFL) in
Switzerland, and we evaluate the sufficient condition (20) in
Theorem 2 by using the actual specification of the mobile
robot.

For the simplicity of the analysis, we assume that \(k_1 = k_2\)
in the gain matrix \(K\). Then the three inequalities to be
satisfied can be reduced to the following two conditions:
\[
(k_1 \bar{v} + 2k_1^2 L) < -\bar{v} + 2k_1
\]
\[
(2k_1 \bar{v} + k_1^2 L) < -2\bar{v} + k_3
\] (28) (29)

In addition, for the above inequalities, we set \(\bar{v} = 0.146[m/s]\) which is about the possible maximum velocity
of the actual mini robot. Since $k_i$ are positive constants, the inequality (28) means that there exists the allowable length of time-delay $L$ for all $k_1 > \frac{v}{2} = 0.073$ and the time-delay satisfying (28) is given by

$$0 \leq L < \frac{2k_1 - \bar{v}}{k_1(2k_1 + \bar{v})}.$$  

In the same way, the inequality (29) means that there exists the allowable time-delay satisfying (29) is

$$0 \leq L < \frac{k_3 - 2\bar{v}}{2k_1 \bar{v} + k_3^2}$$

for all $k_3 > 2\bar{v} = 0.292$.

From the above discussion, we can conclude that if we choose a triplet $(k_1, k_3, L)$ satisfying

$$\begin{align*}
  k_1 &> \frac{\bar{v}}{2} = 0.073 \\
  k_3 &> 2\bar{v} = 0.292 \\
  L &< \min \left( \frac{2k_1 - \bar{v}}{k_1(2k_1 + \bar{v})}, \frac{k_3 - 2\bar{v}}{2k_1 \bar{v} + k_3^2} \right),
\end{align*}$$

(30)

the prediction error converges to zero and the proposed predictor based on synchronization works well. Fig. 5 shows the boundary surface given by (30) for $k_1, k_3 \in [0, 6]$.

Next, we present simulation results that demonstrate the effectiveness of the proposed scheme in a remote tracking control of the mobile robot. Setting $k_1 = k_2 = 0.1$, the relationship between the gain $k_3$ and the maximal allowable length of time-delay $L$ is shown in Fig. 6, which is a cross-section of Fig. 5 at $k_1 = 0.1$. This figure means that if we choose a point in the region enclosed by the $k_3$-axis and the blue line, the prediction error asymptotically converges to zero.

We choose the gains of the predictor (15) as $k_1 = k_2 = 0.1$ and $k_3 = 0.65$, and the tacking controller is given by

$$\begin{align*}
  \omega(t) &= \omega_d(t) + \frac{\lambda_1 v_d(t) y_e(t) \sin \theta_e(t)}{1 + x_e^2(t) + y_e^2(t)} + h_{\lambda_2}(\theta_e(t)) \\
  v(t) &= v_d(t) \cos \theta_e(t) + h_{\lambda_3}(x_e(t))
\end{align*}$$

where $\lambda_1 = 0.01$, $\lambda_2 = 5.00$, $\lambda_3 = 0.115$ and $h_{\lambda_i}(s) = \lambda_i \tanh(s)$ for $i = 2, 3$.

We show some simulation results in a case of the time-delay $L = L_1 + L_2 = 0.75[\text{sec}]$, which corresponds to the
round-trip time (RTT). Fig. 7 shows the desired trajectory and the trajectory of the mobile robot on horizontal plane. As can be seen from this figure, the mobile robot tracks the given trajectory asymptotically. The prediction error is shown in Fig. 8 and the tracking error defined by eq. (17) in Fig. 9. In addition, Fig. 10 shows the forward velocity $v$ and the steering velocity $\omega$ of the mobile robot, which related with the inputs $v_1$ and $v_2$ by eq.(2). From these figures, we know that the prediction error rapidly converges to zero and in turn the tracking error also goes to zero under the input saturation. Therefore we can conclude that the mobile robot can track the desired position with delay $L_1$.

5. CONCLUSIONS

In this paper, we considered the tracking problem for a two-wheel mobile robot via information networks. In particular, we focused on the effect of time-delays caused by the data transmission. To compensate the performance degradation of systems due to the delays, we proposed a state prediction-based tracking control strategy for the mobile robot. The predictor used in the proposed control scheme is based on an anticipating synchronization, which is an extension of chaos synchronization. The state prediction control using the synchronization has been already proposed in our previous work, but we showed that the similar strategy is useful for a two-wheel mobile robot which is a driftless non-holonomic system. Furthermore, we derived a sufficient condition for the prediction error to converge to zero by using the Lyapunov-Razumikhin theorem.

REFERENCES