High Performance Position Controller Design of a Linear Induction Motor for Automatic Picking System Using Integral Sliding Mode Control

Jung-Hyun Choi¹, Sanghoon Kim², Dong Sang Yoo² and Kyeong-Hwa Kim³

¹, ³ Department of Electrical and Information Engineering, Seoul National University of Science and Technology, 232 Gongneung-ro, Nowon-gu, Seoul, 139-743, Korea
² Electrical, Electronic, and Control Engineering, Hankyong National University, 327 Chungang-no, Anseong-si, Kyonggi-do, 456-749, Korea
{Kyeong-Hwa Kim, k2h1@seoultech.ac.kr
³ Corresponding Author

Abstract. To implement an automatic picking system (APS) in distribution center with high precision and high dynamics, this paper presents a design of a linear induction motor (LIM) drive and robust position controller based on an integral sliding mode control (SMC) scheme. The force disturbance as well as the mechanical parameter variation such as the mass and friction coefficient influences directly on the position control performance of APS. To guarantee a robust control response in the presence of such uncertainty, an integral SMC-based position controller is designed.

Keywords: APS, Integral SMC, Linear induction motor, Parameter uncertainty, Position control.

1 Introduction

To cope with a recent environmental change in the distribution industry as well as a change in consumer’s spending pattern, many interests have been focused on the development of the advanced distribution system such as an automatic picking system (APS) which can effectively handle the order in small and diverse products [1], [2]. A linear driving mechanism with high accuracy has been recognized as an essential component to realize a movable ejector in the APS.

To implement a movable ejector in the APS with high precision and high dynamics using the linear motor, an issue on the design of a high performance linear motor drive system has become a major concern in the related fields. Recently, several works have been studied to control the position of a linear induction motor as a single unit without considering the APS [3], [4]. However, the scheme in [4] is too complex to apply in the physical APS. Even though the compensation methods using a model reference adaptive control or the load torque observer have been developed to improve the control performance [5], [6], they work well only when the variation of an unknown disturbance is not large during sampling interval. Using these approaches,
it is difficult to estimate the parameter variation effect because some parameter
mismatch like the mass produces a disturbance proportional to acceleration.

In this paper, a high performance robust position controller design of a linear
induction motor (LIM) for an APS using the integral sliding mode control (SMC) is
presented, which can operate the movable ejectors of the APS with high dynamics
and high precision in the stage of the pick-up, transportation, and sorting of logistics.
The proposed scheme is achieved by the integral SMC [7] to guarantee a robust and
accurate response by applying the discontinuous control input through switching logic.

2 Robust position controller design

The structure of a single-sided three-phase LIM is shown in Fig. 1, which is
composed of the primary and secondary sides [8]. Three-phase windings with
sinusoidal distribution are placed on the primary side similar to the stator of a rotary
motor. The secondary side consists of a sheet conductor with a back iron for the
return path of the magnetic flux.

The field-orientated control is generally employed to decouple the dynamics of the
thrust force and the flux amplitude of the LIM [9].

Fig. 1. Configuration of a LIM.

The thrust equation of the LIM is expressed as follows:

\[ F_e = K_t (\lambda_{ds} i_{qs} - \lambda_{qr} i_{ds}) = (Mp + D)v_m + F_L. \]  \hspace{1cm} (1)

where \( K_t \) is the thrust constant, \( M \) is the mass of the mover, \( D \) is the friction
coefficient, \( v_m \) is the linear velocity, and \( F_L \) is the external thrust disturbance. To
ensure a robust position control performance of the APS in the presence of the
variation of mechanical parameters, the position controller for the LIM is designed
based on the integral SMC, which consists of an equivalent control input and a
switching control input. In this paper, the variations of the mass, friction coefficient,
and external thrust disturbance are considered for the mechanical parameter variation.

A sliding surface of the integral SMC can be defined as follows:

\[ s = x_2 + \beta x_1 + c \int_{-\infty}^{\tau} x_1 d\tau = 0. \]  \hspace{1cm} (2)
where $x_1$ is the position error of the mover and $x_2$ is the speed error. Using (2), the dynamic characteristics of the control system on the sliding surface can be easily assigned by $\beta$, $c$ and the initial value of integrator. The initial value of integrator should be set at $t=0$ to generate the sliding mode even during the whole transient period. The equivalent control input $u_{eq}$ can be obtained from (2) and the conditions of $f=0$ and $\dot{s}=0$ as

$$u_{eq} = \frac{M_o}{K_p \dot{r}_{dr}} \left( \frac{D_o}{M_o} x_2 - \beta x_2 - c x_1 \right).$$  

(3)

The switching control input $\Delta u$ to maintain the states on the sliding surface consists of a discontinuous function and can be expressed as follows:

$$\Delta u = \frac{M_o}{K_p \dot{r}_{dr}} \rho \cdot \text{sgn}(s) = \frac{M_o}{K_p \dot{r}_{dr}} \rho \cdot \frac{s}{|s|}.$$  

(4)

### 3 Simulation results

In this section, comparative simulation results are presented to verify the robust control performance of the LIM for the APS. The whole system consists of a LIM, a current controller, a field-oriented controller and a PWM inverter. For a current control algorithm, the synchronous PI decoupling scheme is employed. The sampling period is set to 100 [$\mu$sec], which yields a switching frequency of 10 kHz in the PWM inverter.

![Fig. 2. Control performance of the PI position controller and integral SMC position controller under five test conditions. (a) PI controller (b) Integral SMC.](image)

Fig. 2(a) shows the responses of the PI position controller under five test conditions when the position reference is 1[m]. Although this control gives a
relatively good performance under the nominal mechanical parameter values such as in the test condition 1, its response is not satisfactory under the parameter variations. Under the mass variation, the transient responses tend to be sluggish. On the other hand, a steady-state position error is observed under the existence of external disturbance.

Fig. 2(b) shows the responses of the integral SMC-based position controller under the same test conditions. The position responses of this control yield almost similar waveforms under five test conditions irrespective of the mechanical parameter variation. This comes from the fact that the state error can be always maintained on the sliding surface without reaching mode according to initial conditions.

4 Conclusion

This paper presents a design method for the servo drive and robust position controller of a LIM based on an integral SMC scheme to operate APS equipments with high precision and fast dynamics. To get robust position control characteristics under the uncertainty such as the disturbance thrust and the mismatch in mass or friction coefficient, an integral SMC-based position controller has been designed. Comparative simulations have been done under five different conditions using the developed Simulink model for the LIM. As a result, it has been proved that the proposed scheme has a robust control nature and is an effective way for APS.

Acknowledgements. (GRRC Hankyong 2012-B02), Development of An Automatic Picking System with Traveling Dispensers using Linear Motors

References