AGV Steering Controller using NN Identifier and Cell Mediated Immune Algorithm

Young-Jin Lee, Jin-Ho Suh, Jin-Woo Lee, and Kwon-Soon Lee

Abstract— **In this paper, CMIA (Cell Mediated Immune Algorithm) controller was proposed to drive the autonomous guided vehicle (AGV) more effectively. The proposed controller was based on specific immune response of the biological immune system which is the cell mediated immunity. To verify the performance of the proposed CMIA controller, some experiments for the control of steering of that AGV are performed. The tracking error of the AGV was mainly investigated for this purpose. As a result, the capability of realization and reliability were proved by comparing the response characteristics of the proposed CMIA controllers with those of the conventional PID and NNPID(Neural Network PID) controller.**

I. INTRODUCTION

The PID controller has been widely applied to the most control systems because of its simple structure and easy designing. One of the important points to design the PID control system is to tune the approximate control parameters for the given target system. To find the PID parameters using traditional control methods should be needed a lot of experience and experiments to ensure the optimal performance.

This paper wishes to develop new control system that can correspond as being strong in external environment by introducing immunity system to solve difficulty of such parameter design. Field that is applying immunity system in engineering field divides by humoral immune response(HIR) and cell-mediated Immune response(CMIR) greatly and they are becoming research recently. The humoral immune response is applied in many fields such as optimization technique, robot group control, distributed self-regulation robot controller [1]-[3]. Cell-mediated immune response is applied using cellular reaction model, but it is real condition that is not so many [4]-[6].

For the most part, the general method for control of this system is designing suitable controller to require condition through model analysis of that which is controlled object system. However, it is hard that composes correct model because AGV system has nonlinearity strongly and it must be satisfied with assumption that has nonholonomic system constraints. Moreover, even if we assume that is known correct model or parameter, it is difficult to control this system, because it must be considered external changes of environment such as various load fluctuations or change of road states when it is run in the outdoor.

That is, we wish to compose to control system of engineering field using cell-mediated immune responses of these immune systems, and wish to apply in AGV's driving control to estimate excellency of control system performance and realization possibility that is planed. Moreover, we used the Neural Network Identifying technique to model for each speed and steering department of the AGV system because it has characteristic that can forecast future output of the system from past information. And then, we can overcome nonlinearity and complexity of actual AGV system.

In this paper, we manufactured an AGV system and performed some experiments to verify performance of controller planed with something wrong. Also, we wish to verify possibility and excellency as adaptation controller by investigating displacement error about trajectory each, and compare the response characteristic with usual PID controller and Neural Network PID(NNPID) controller.

II. IMMUNE SYSTEMM

Biological Immune system can be divided by the first defense and the second defense. The first defense as integument, person's body has been covered with skin and mucus membrane and can intercept external invasion material effectively. However, if such the first defense is collapsed, the body achieves protection function constructing new second line of defense that is spoken as the second defense. The second defense can be divided by nonspecific defense and specific defense again. Nonspecific defense is direct and quick, and though chemical and particular Leukocyte are used, these defense materials have feature that can always correspond immediately in stand-by status. Reaction acts as nonspecific defense by chemical reaction and Phagocytes such as Histamine of skin, Complement, Interferon and base Basophil.

In the meantime, specific defense is more complicated and need some time to prepare the defense materials usually. B and T Lymphocytes are used to compose this specific defense system. B lymphocytes as cell are produced in Bone Marrow, B cell of about 10^{12} different kinds exist in the human's body, and B cell is active on memory cell. This time, antibody promote phagocytosis of phagocytes such as macrophages and leukocyte through opsonization.

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Y. J. Lee is with the Department of Electrical Instrument and Control, Korean Aviation Polytechnic College, Korea airlee@kopo.or.kr

J. H. Suh and J. W. Lee are with the Department of Electrical Engineering, Dong-A University, Korea suhgang@hanmail.net, jinwoo@donga.ac.kr

K. S. Lee is with the Division of Electrical, Electronics, and Computer Science, Dong-A University, Korea kslee@daunet,donga.ac.kr

Specially, B cell which is differentiated on memory cell can maintain immunity, and react urgently when caught again. That is, antibody secretion phenomenon, such specific chemical reaction, is known as humoral immunity reaction [7] [8]. T cell(T lymphocyte) that compose another the specific second defense system is consisted of three kind of cell such as T-helper cell(T_h), T-suppresser cell(T_s), and T-killer cell(T_k) greatly as cell that produced by thymus. These T cells do cell-mediated immunity effect which interact directly in cells invaded by virus or carcinogen material etc., and T_h cell activates B cell, and T_s cell controls immune actions [6] [9].

III. CMIA CONTROLLER

A. Basic theory of the cell-mediated immune response

Relation of cell-mediated immunity is deep with main meals cell and T cell. T cell is consisted of three parts(T_s, T_h, T_k) greatly, and T_s controls immune response, T_h helps the others, and T_k destroy pathogenic bacteria directly. Analogously, Macrophages stimulates humoral immunity cooperating with T cell, and Macrophages activated does strong Phagocytosis. Except complement great Phagocyte, T cell and antibody destroy province and pathogenic bacteria directly do. Specially, main reaction mechanism can appear with Fig. 1 as immunocyte that T cell features in humoral response and cell-mediated immune response.

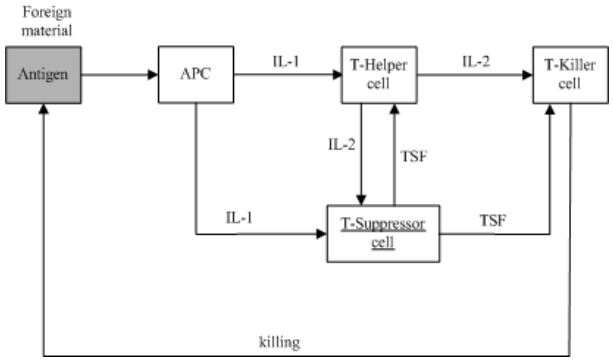


Fig. 1. The T cell regulation mechanism

As show in Fig. 1, if antigens(Ag) are invaded from outside, antigen presenting cells(APC) that inform the fact tainted from these secrete interleukin-1(IL-1), and then pass the information to T_h. This time, T_h is being activated and then stimulate B cell, T_k cell and T_s by secreting interleukin-2(IL-2). Also, T_s do act role of control mechanism that secrete TSF(T-Suppressor Factor) and control T_h, B cell, and T_k's excitement. Through such series control process, immune system has function that recover state that stabilize and protect own from stuff and material simultaneously invaded from outside [8]. Therefore, we wishes to design intelligence control construction with more adaptability and flexibility in dynamic environment using modeling mathematically self-adjustment process of this immune system.

B. Cell-mediated immunity using the cellular molecular kinetics

Cellular Molecular Kinetics model becomes basis of all immune response as being based to conservation law or mass action principle of chemistry. From this model, we can do model the relation of immune response. Eq. (1) shows general model of cell-molecule power science [9] [10].

$$\begin{aligned}\frac{dX_i}{dt} &= V_i(t) - \frac{X_i}{tau_i} + P_i(\cdot)X_i + \sum_{j\neq i} 2P_j(\cdot)X_j \\ &\quad - \sum_{k\neq i} 2P_k(\cdot)P_{ik}(\cdot)X_k \end{aligned} \tag{1}$$

Here, X_i is cellular number, $V_i(t)$ displays source term from outside(through blood from marrow), and τ_i is death time constant, $P_i(\cdot)$, $P_{ji}(\cdot)$, $P_{ik}(\cdot)$ are suitable cell growth coefficient $(\cdot)$ relevant cells appear respectively.

Recently, mathematical models of cancer-immunity are reported based on this cellular molecular kinetics. Immune response processes with antigen and T cell can be modeled from eq. (1). That is, we can get model such as eq. (2) if consider reaction mechanism for only T cell from eq. (1) [1] [9].

$$\begin{aligned}\frac{dx_1}{dt} &= p_1x_1 - \frac{x_1}{\tau_1} - p_{31}x_1 \\ \frac{dx_2}{dt} &= p_2x_2 - \frac{x_2}{\tau_2} - p_{31}x_2 \\ \frac{dx_3}{dt} &= p_3x_3 - \frac{x_3}{\tau_3} - p_{31}x_3 \\ \frac{dx_4}{dt} &= p_4x_4 - \frac{x_4}{\tau_4} - p_{31}x_4 \end{aligned} \tag{2}$$

Here, x_1, x_2, and x_3 display T_h, T_k, and T_s cell respectively, and x_4 displays antigen. Also, p_i is the growth coefficient of antigen and each cell. p_{23} and p_{24} are cell activation coefficient that express degree of reaction which T_s'control element and T_k for each other cell remove antigen. All of those control degree of immune response.

C. Design of the CMIA controller

In this paper, we designed CMIA controller through some assumption from eq. (1). First, if T_k destroy and remove this acting directly in antigen, T_h and T_s help or control each other in actual immune system. Therefore, if antigen $\epsilon(t)$ that is invasion material from outside on t times time is happened, occurrence of external material is informed by APC in immunocyte in living body. From this T_h and T_s according to proliferating function by eq. (3) and eq. (4) stimulus and control the immune response [6].

$$P(\epsilon) = H_{max} + \frac{H_{min} - H_{max}}{1 + (\frac{\epsilon(t)}{C_h})^{g_k}} \tag{3}$$

$$TSF(\Delta T_k) = S_{max} + \frac{S_{min} - S_{max}}{1 + (\frac{\Delta T_k}{C_S})^{g_k}} \quad (4)$$

Here, $P(\epsilon)$ and $TSF(\Delta T_k)$ display cell activation function and cell control function respectively. $\epsilon(t)$ displays the antigen and H_{max}, H_{min}, S_{max}, and S_{min} that are external invasion material expresses the necessary maximum and smallest reaction amount in cell growth. They can fluctuate by ratio according to the external invasion amount and ΔT_k as that antigen. Also, C_h, g_h, C_s, and g_s are the parameters about cellular growth speed. Each cells(T_h, T_s, T_k) can consist of immune response by these two eq. (3) and eq. (4). Also, if the focus to fact that it is T_k that act opposing directly in the antigen, T_k can displays eq. (5) because it is regulated by $P(\epsilon)$ and $TSF(\Delta T_k)$.

$$T_k(t) = K_k\{P(\epsilon) - TSF(\Delta T_k)\} \quad (5)$$

Here, T_k depends on change amount of $\epsilon(t)$ and regulation amount of T_h and T_s as antigen killing cell and K_k displays T_k's growth element. Fig. 2 displays the control mechanism of T cells.

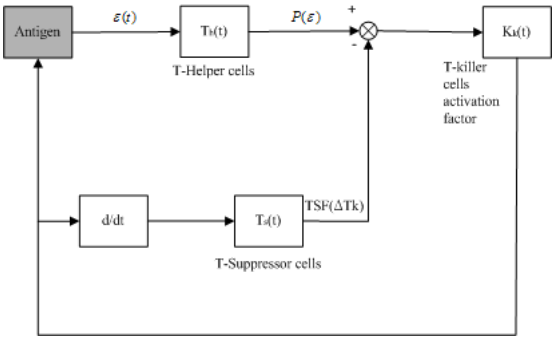


Fig. 2. The T-cell regulation mechanisms based on the CMI

Therefore, this immune response can control antigen that invade from outside being regulated spontaneously in the body and is kept the body in stable state. Also, cell activation function and control function of eq. (3) and eq. (4) can be considered as design parameter that decide performance of controller. Eq. (4) of $T_k(t)$ can be considered by control amount $U(t)$ that control system in engineering field because $T_k(t)$ removes this fighting directly with antigen. This time, ΔT_k can be considered as $\Delta U(t)$ that is control amount change of controller, $\epsilon(t)$ can be thought by $e(t)$ that is the error of system output, and K_k that is T_k's growth element can be considered to scale factor of controller. From these results, we can design of the controller using cell-mediated immunity as eq. (6) from similarity with cell-mediated immune response and PID controller.

$$\begin{aligned} U_{CMIA}(t) &= K_1\{P_P(e) - TSF_P(\Delta u)\}e(t) \\ &+ K_2\{P_1(\int e) - TSF_1(\Delta u)\}\int e(t) \\ &+ K_3\{P_D(\Delta e) - TSF_D(\Delta u)\}\frac{de(t)}{dt} \end{aligned} \quad (6)$$

Here, K_1, K_2, K_3 are scaling element of control gains, $P(\cdot)$ are considered proliferating factor of the control amount, and $TSF(\cdot)$ are considered suppression factor compared with proportional, derivative, and integral terms in the controller parts. Also, next conditions should be satisfied to act within stable area that controller is robust. K_1, K_2, $K_3 > 0$, $P(\cdot) > 0$, and $TSF(\cdot) \geq 0$'s conditions are satisfied. And H_{max}, $S_{max} > 0$, H_{min}, $S_{min} = 0$, and C_h, $C_s > 0$ should be become. The designed control system of our research can be guaranteed in the convergence and stability under these conditions.

IV. AGV SYSTEM AND IMPLEMENTATION OF CMIA CONTROLLER

A. Hardware of AGV system

Composition of the AGV that be manufactured in this paper can be sectionalized 4 parts which are control department, drive department, communications department, and sensor department greatly. First, control department is composed two parts which are personal computer(PC) and 80C196 microprocessor to control AGV system and to run control algorithm. The main program(or algorithm) that can process also image information getting from vision sensor run on the PC that is composed Pentium 586III. Also, information about traveling by driving displacement error that get from reflex acquired in PC composed to be transmitted by 80C196 through RS232 communication and exchanges necessary information in controller drive. In the 80C196, each control algorithm is process, it can get the speed data and steering data from each sensor, and generate drive signaling for each motor. Fig. 3 shows AGV's whole system that has composition such as above structure and Fig. 4 shows AGV simulator that we manufactured in this paper.

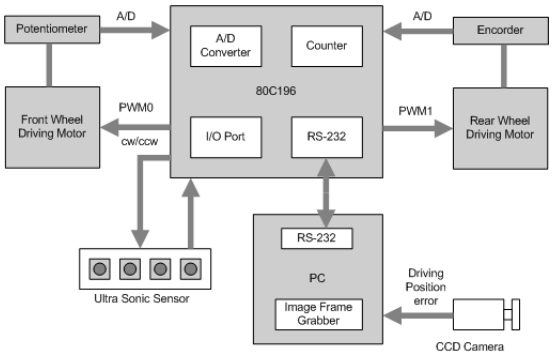


Fig. 3. The AGV system scheme

Therefore, we used CCD camera to get location and driving information of AGV traveling by driving path. That is, we utilized sensor to get error about guideline and relative location with AGV and angle that is guide. Fig. 5 shows process to get relative displacement error e_d and

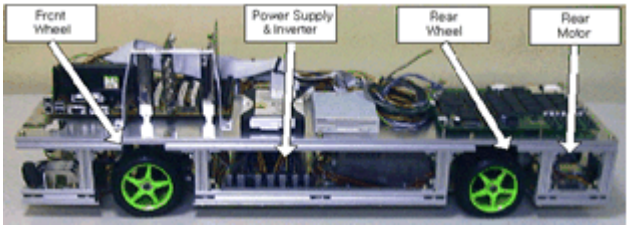


Fig. 4. Side view and each module of AGV

angle error α to decide reference steering angle δ in the image information. To get δ, we feedback the displacement error and we feed forward the angle error of guide line with estimate element.

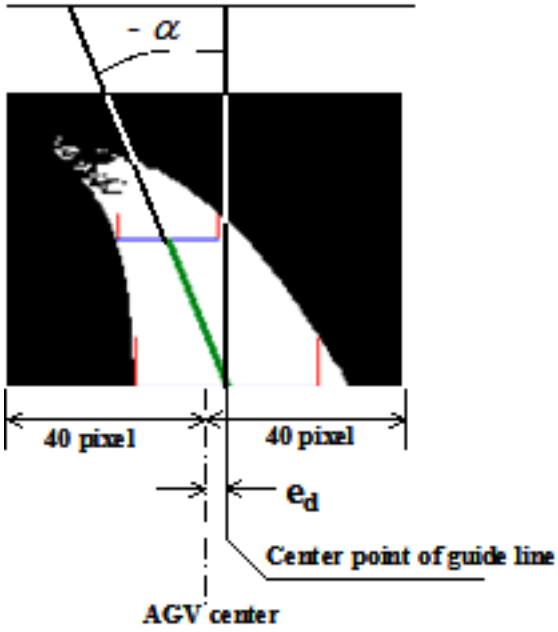


Fig. 5. The relative errors of distance and angle between the AGV and guideline

If AGV's speed increases while the setting speed regulates R_{speed}, ration is increased angle error more than displacement error, otherwise it weighted in displacement error relatively if the speed decreases. Also, we did get δ from scaling of whole value of part that become feed forward and feedback by gains K. Through these process, standard steering angle δ can be shown follow eq. (7).

$$\delta = K\{(\frac{e_d}{R_{speed}}) + R_{speed} \cdot \alpha\} \quad (7)$$

B. Implementation of the Neural Network identifier

In this paper, we used neural network identification techniques to model at AGV system with nonlinearity. This technique has function that can forecast future output from learning past information. We can get more approximation modeling of the AGV system without complicated classical mathematical modeling process. Eq. (8) shows the structure of neural network with parallel modeling structure [11].

$$\begin{aligned} \hat{y}_p(k+1) &= N^2[\hat{y}_p(k), \cdots, \hat{y}_p(k-n+1)] \\ &\quad -N^1[u(k), \cdots, u(k-m+1)] \end{aligned} \quad (8)$$

Parallel structure has the function that can forecast output of plant separatively with plant if learning for plant is completed. N^1 and N^2 are considered AGV dynamics of the steering and driving system respectively. $[y(k), u(k)]$ are the input and output factor of AGV respectively. For learning of NN, we used PWM signal for input data and A/D and counter data for output data. For output data, we used A/D and counter data. The structure of neural network for learning is used multi-layer neural network. Also, identity function is used for activation function to decide Neuron's reaction degree when learning. The pattern number, input layers, and hidden layers are used for neural network identifier of the AGV, 700, 5, and 7, respectively. The learning rate is 0.9 and momentum value is 0.3. Fig. 6 shows identification result of neural network of steering system.

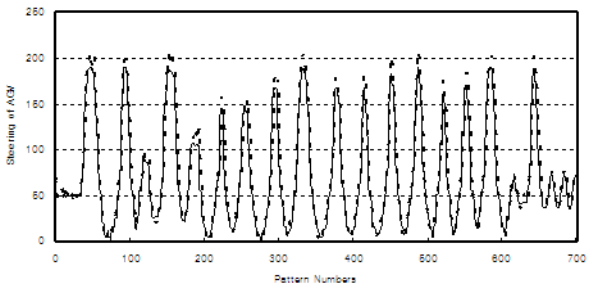


Fig. 6. Results of the neural network identification for the steering system

Average value of percent error for neural network identification was about 15%. However, case of thing outside that modeling error is big in maximum value can know that error is almost not happened. Fig. 7 shows the modeling wave of speed system. Average of percent error was 6.9%.

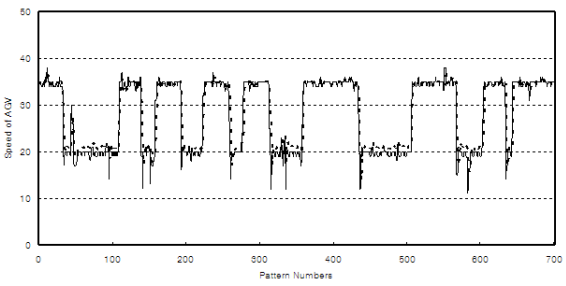


Fig. 7. Results of the neural network identification for the speed system

C. Optimal design of CMIA controller

For CMIA controller that proposed in this research, regulation of most suitable value is required in reply because controller parameter that include nonlinearity element should be considered when designing. Fig. 8 shows auto tuning structure for CMIA control parameter using HIA(Humoral Immune Algorithm). While tuning the control parameter automatically, HIA's generation did to 100, individual number for each generation did 40, and population number stored in memory cell did 10. To create new individual 50% was used for random sampling 50% was also used for reproduction of old individual. And then genetic crossover is used and mutation probability is used 0.25%.

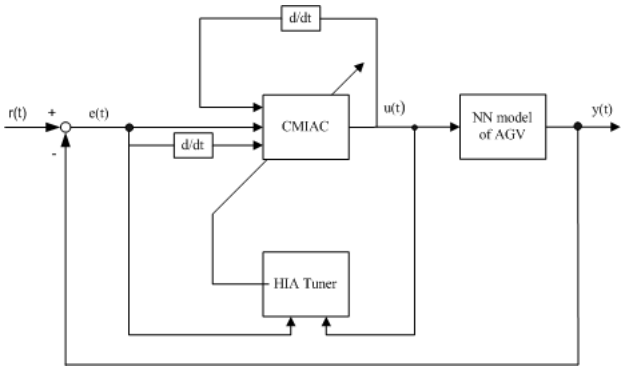


Fig. 8. The HIA tuned CMIA control system

For CMIA controller design, g_s and g_h put by 1 together to reduce nonlinear element so far as possible. All the 14 parameters that are K_1, K_2, K_3 and H_{max} of each function, C_h, C_s, and S_{max} of $TSF(\Delta u)$ function are adjusted using HIA for most suitable controller design.

V. EXPERIMENTAL RESULTS

For AGV's traveling by driving experiment, sine wave path is used actually as shown Fig. 9. The path and traveling by driving place is used in an actuality traveling. Amplitude of traveling by driving path did $1[m]$ and the line is white with $1[cm]$ width.

Fig. 10 shows the experimental results by driving displacement error for PID, NNPID, and CMIA control when AGV driving in $0.5[m/sec]$ speeds with load of $25[kg]$.

As the results, proposed CMIA control was improved 17% and 16% than PID and and NNPID control for the maximum displacement error proposes respectively. Also, in case of displacement error happened averagely in traveling, our CMIA controller was improved 27% and 20% than PID and NNPID control, respectively. Although we did not appear by picture for speed control parts, CMIA controller is improved more than about 60% as about 2.5% others, whereas overshoot of about 5.5% of PID control happens.

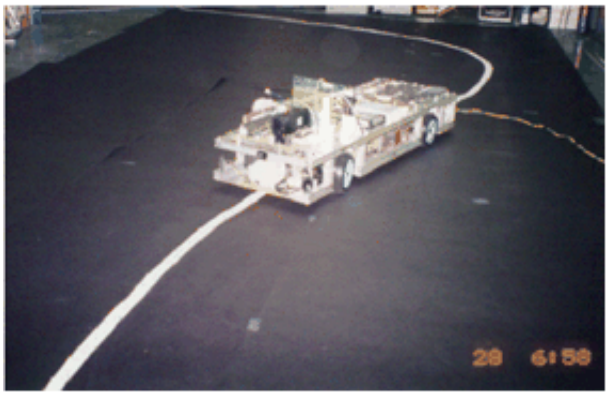
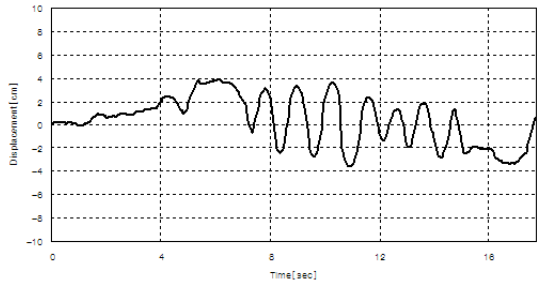
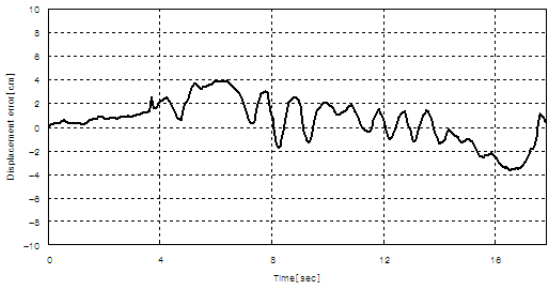


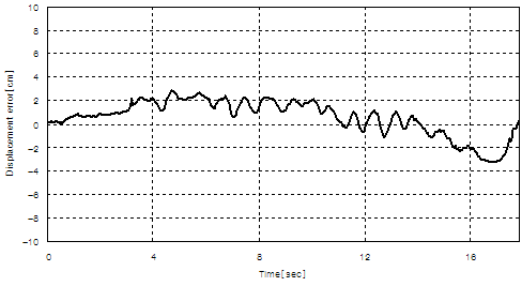
Fig. 9. The photograph of the AGV driving experiments



(a) PID



(b) NNPID



(c) CMIA

Fig. 10. The results of neural network

VI. CONCLUSION

The objective of this paper is to develop the new robust and adaptive control system against external environments as applying the probabilistic recognition that is one of the inherent properties of immune system, ability of learning and memorization, and regulation theory of immune network to the system under engineering point of view. In this paper, CMIA(Cell-Mediated Immune Algorithm) controller that based on specific immune response of the biological immune system that is the cell-mediated immunity was proposed to drive the autonomous guided vehicle(AGV) more effectively.

However, AGV system is highly recommended to enhance the productivity by ensuring the stable and speedy transportation. On this case, each controller must be designed to have the adaptiveness for the load fluctuation or environmental change.

In this paper, to verify the performance of the proposed CMIA controller, some experiments for the control of steering and speed of AGV system are performed. The tracking error of the AGV was mainly investigated for this purpose. As the results, the capability of realization and reliability was shown by comparing the between response characteristics of the proposed CMIA controller and conventional controllers such as PID and NNPID.

VII. ACKNOWLEDGEMENT

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