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PID Tuning Method on AGV (Automated Guided Vehicle) Industrial Robot

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Abstract

Controlling a system can be done in various ways and methods. The classical method which even now a day as a solution works is PID which in that with some method three-parameter of controller called P (Proportional), I (Integral), D (Derivational) tuned to have the best controlling response from a system. The AGV robot as the abbreviation of the Automated Guided Vehicle is as a famous robot platform which used in various industries relies on PID controllers in various ways. Each AGV or Machine has its own set of function, hence, in order to accomplish the exact set of workload more efficiently one need to actually tune the PID parameters accordingly so that there cannot be an intolerable amount of energy loss, inefficiency rate, lag, lack of robustness etc. In this paper over than introduction of PID controller and see the effect of each parameter on the real system the compassion between hired methods on AGV robot are investigated. As this review indicates that various PID tune method are used based on system requirements with the help of Lyapunov Direct Method, traditional Ziegler Nichols, Fuzzy controller, human immune system called the humoral, neural network, etc to control the speed and steering of an AGV systems.

Keywords: PID, AGV, PID Tune, Ziegler-Nichols, Automated Guided Vehicle

1. Introduction

A Proportional-Integral-Derivative controller (PID controller) is a generic controller widely used in industrial control systems. A PID controller continuously calculates an error and applies a corrective action to resolve the error [1]. On the other way, the controller compares the collected data with a reference value, and then uses this difference to calculate a new input value. The purpose of this new input value is to allow the system data to reach or maintain the reference value. Unlike other simple control operations, the PID controller can adjust the input value based on historical data and the occurrence rate of the difference, which can make the system more accurate and stable. It can be proved through mathematical methods that a PID feedback loop can keep the system stable, when other control methods cause the system to have a stable error or a process is repeated that is put the system on loop. The main reason for having a PID controller is error correction and control management and it can be applied in various field like: motor speed control, car cruise control, temperature [2]. Along with mentioned application and due to vast application of this controller on motor speed, the automated guided vehicle (AGV) is also hired the PID routine to correct tracking, power, speed, robustness, steering and a lot of other parameters that have uncertainty. The PID control equation involves three separate parameters; the Proportional, the Integral and Derivative terms.

AS the PID name shows, to tune this controller ,

three parameters of Scale (term P), Integral (Term I), Differential (term D) as shown in equation (1) are involved.

$$U(t) = K_p e(t) + K_i {}^{de(t)}/_{dt} + K_d \int e(t)\, dt \tag{1}$$

Equation 1 is the general equation for PID controller which K_p is proportional, gain, K_d is derivative gain and K_i is integrator gain. PID is named after its three correction algorithms. All three algorithms use addition to adjust the value being controlled. In fact, most of these additional operations become subtraction operations because the added number is always negative. The three algorithms are:

Proportional (Scale)

To control the present, the error value is multiplied by a negative constant P (for scale) and then, added to the predetermined value. P is only true when the output of the controller is proportional to the system error. This controller output change is proportional to the deviation of the input controller [3].

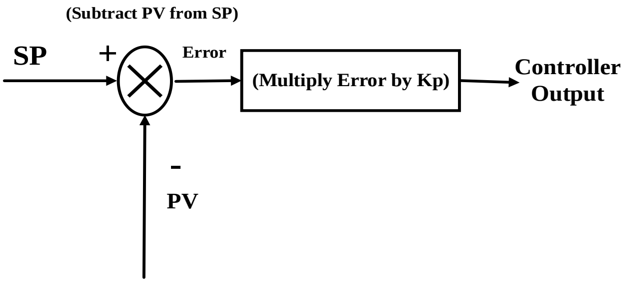

Figure (1). The P controller

Integral

To control the past, the error value is the sum of the errors over a period. Afterwards, multiplied by a negative constant I and afterwards added to the predetermined value. In the other words, the average error of the output of the system and the predetermined value from the past average error value can be defined as this term. [3].

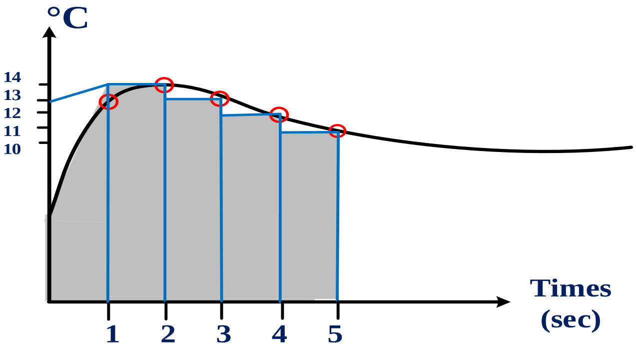

Figure (2). The I controller

As brief, in Integral only mode, the controller multiplies the integral of the error (accumulation of error or part under the error curve) by the Integral Gain (Ki) to get the controller output.

Differential or Derivative is just a mathematical term meaning rate-of-change. This term used to control the future, calculate the first derivative of the error, multiply it by a negative constant D, and finally add it to the predetermined value. The control of this derivative will respond to changes in the system. The larger the result of the derivative, the faster the control system responds to the output. The D- parameters help reduce short-term changes in the controller. Some practically slow systems may not require D parameters. In more specialized terms, a PID controller can be called a filter in a frequency domain system. This is useful in calculating whether it will eventually reach a stable result. If the value is not selected properly, the input value of the control system will oscillate repeatedly, which may cause the system to never reach the pre-set value [3].

In Derivative Only mode, the controller simply multiplies the rate of change of the error at that instance (slope of the error curve) by the Derivative Gain (KD) to get the controller output. In this paper first, the Different Controller Types with the effect on step response are described in Section II. Then, the PID Tuning method is reviewed in Section III. In section iv, the AGV PID Tune methods are discussed and Finally, the paper has concluded in section V with the controller performance and PID methods used AGV systems.

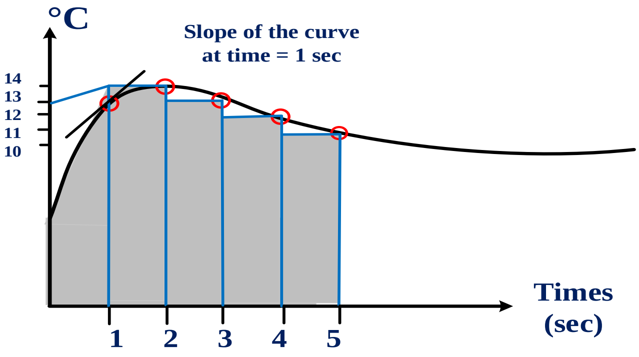

Figure (3). The D controller

1- *Different Controller Types*

Although different types of controllers have different structures and principles, there are only three basic control laws: proportional (P) control, integral (I) control, and derivative (D) control (Figure (4)).

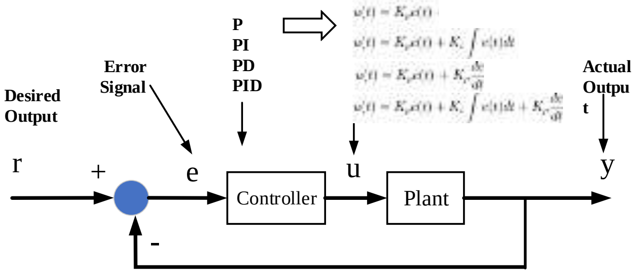

Figure (4). The controller Types and structure

As shown in Figure (4), these kinds of control laws can be used individually, but more occasions are used in combination. Such as proportional (P) control, proportional-integral (PI) control, proportional-integral-derivative (PID) control, etc. which are described as following

- **Proportional (P) control**

Separate proportional control is also called "difference control". The change in output is proportional to the deviation of the input controller. The larger the deviation, the larger the output. In practical applications, the size of the proportionality should be determined according to the specific situation. The proportionality is too large, and the control effect is too weak, which is not conducive to the system to overcome the disturbance. The remaining margin is too large, and the control quality is poor. If the control effect is too strong, it will easily lead to the deterioration of system stability and trigger oscillation.

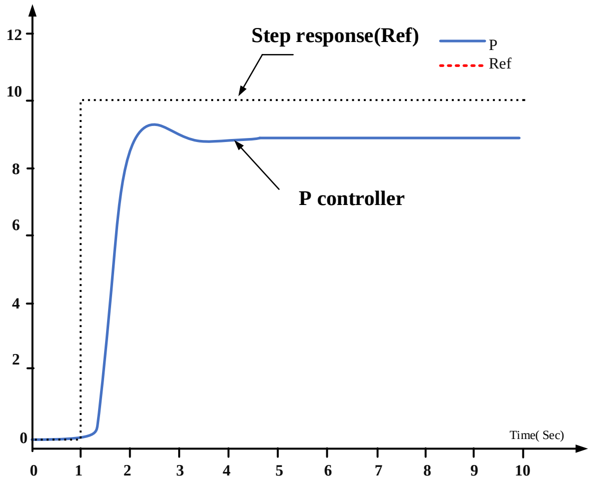

Figure (5). The P controller Vs Step response

For controlled objects with sensitive response and strong amplification ability, in order to improve the stability of the system, the proportionality should be slightly larger; for controlled objects with slow response and weak amplification ability, the proportionality can be selected to be smaller. Increasing the sensitivity of the entire system can also reduce the residuals accordingly. In simpler words, the proportional mode duty is to multiply the Error by the Proportional Gain (Kp) to get the controller output and the Proportional Gain is the setting that can tune to get our desired performance from just the P controller. Simple proportional control is suitable for occasions with small disturbances, small lags, small load changes, and low requirements, which allow a certain margin to exist. The use of proportional control law in industrial production is more common [4].

- **Proportional integral (PI) control:**

The proportional control law is the most basic and widely used one among the basic control laws. Its biggest advantage is that the control is on time and rapidly. If a deviation occurs, the controller immediately produces a control effect. However, the disadvantage of not being able to finally eliminate the residual limits its use alone. The way to overcome the residual is to add integral control to the proportional control. The output of the integral controller is proportional to the integral of the input deviation over time. "Integral" here means "accumulation". The output of the integral controller is not only related to the magnitude of the input deviation, but also to the time that the deviation exists. As long as the deviation exists, the output will continue to accumulate (the output value becomes larger or smaller), and the accumulation will stop until the deviation is zero. Therefore, integral control can eliminate the residual. The law of integral control is also called the law of no difference control.

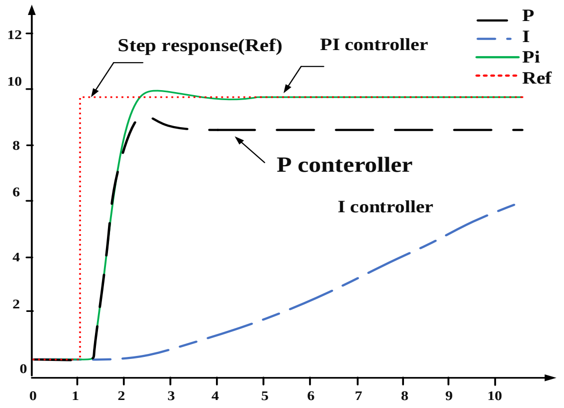

Figure (6). The P, PI, I controller Vs Step response

The integration time characterizes the strength of the integral control effect. The smaller the integration time, the stronger the control effect; otherwise, the weaker the control effect. Although, integral control can eliminate the residual, it has the disadvantage of untimely control. Because the accumulation of the integral output is gradual, the control effect produced by it always lags the change of the deviation, and it cannot overcome the influence of interference in a timely and effective manner. It is also difficult to stabilize the control system. Therefore, in practice, integral control is generally not used alone, but is combined with proportional control to form proportional-integral control. In this way, the strengths of the two, are made up for each other, and both the rapid and timely proportional control function and the ability of the integral control function to eliminate residuals are achieved. Therefore, proportional integral control can achieve a more ideal process control [4]. A proportional-integral controller is the most widely used controller, which is mostly used in liquid level, pressure and flows control systems in industrial production. The introduction of integral action can eliminate the residual, make up for the shortcomings of pure proportional control, and obtain better control quality. However, the introduction of integral effects will make the system stability worse. For control systems with large inertia lag, it should be avoided as much as possible.

- **Proportional Derivative (PD) Control**

Proportional integral control is not ideal for controlled objects with a time lag. The so-called "time lag" refers to: when the controlled object is disturbed, the controlled variable does not change immediately, but there is a time delay, such as the capacity lag. Currently, the proportional-integral control appears sluggish and untimely. For this reason, people assume that the corresponding control action can be made according to the changing trend of the deviation. by having the experienced operators, change the valve opening degree (proportional effect) according to the size of the deviation, and one can predict the situation that will occur according to the speed of the deviation change. This is the law of differential control with "advanced" control. The output of the differential controller depends on the speed at which the input deviation changes [2].

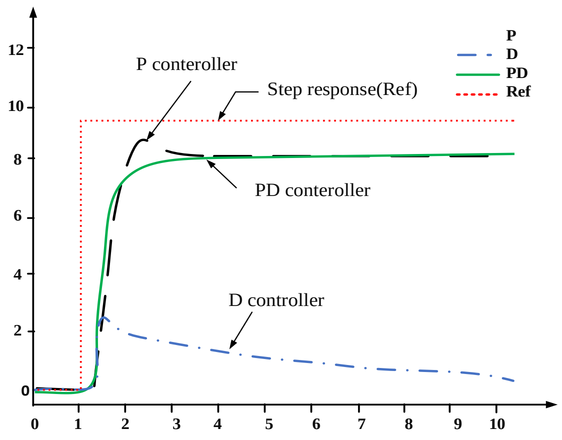

Figure (7). The P, D, PD Vs Step response

The differential output is only related to the rate of the change of the deviation and has nothing to do with the magnitude of the deviation and the existence of the deviation. If the deviation is a fixed value, no matter how big it is, if it does not change, the output change must be zero, and the controller has no control effect. The greater the differential time, the longer the differential output is maintained, and therefore the stronger the differential effect; otherwise, the weaker it is. When the derivative time is 0, there is no derivative control effect. Similarly, the selection of the differential time needs to be determined according to the actual situation. The characteristics of differential control are fast action, advanced adjustment function, which can effectively improve the control quality of the controlled object with a large time lag; but it cannot eliminate the residual, especially for constant deviation input, there is no control at all. Therefore, the differential control law cannot be used alone. Especially, for objects with large capacity lag, the magnitude of dynamic deviation can be reduced, control time is saved, and control quality is significantly improved.

- **PID control**

It combines the strengths of the three P(Proportional), I(Integral), D(Derivational). Then in this controller not only the proportional action is timely and rapid, but also the integral action to eliminate residual capacity, and the advanced control function of the differential action [5].

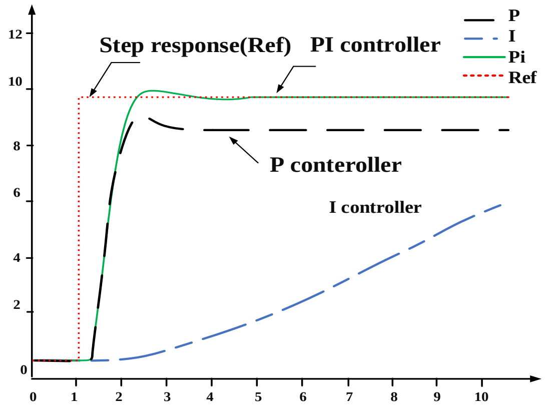

Figure (8). The P, PI, PID controller Vs. Step response

When the deviation step appears, the derivative immediately and greatly moves to suppress this jump in deviation. At the same time, the proportion also plays a role in eliminating the deviation and reducing the deviation range. Because the proportion is a control law that lasts and plays a major role, therefore It can make the system more stable; the integral effect slowly overcomes the residual. If the three control parameters are properly selected, the advantages of the three control laws can be fully utilized to obtain a better control effect.

2- *PID Tuning*

Parameter tuning of the PID controller is the core content of control system design. It is to determine the size of the proportional coefficient, integration time and derivative time of the PID controller according to the characteristics of the controlled process. There are many methods for tuning PID controller parameters, and they can be summarized into two categories [6]:

The first is the theoretical calculation

The first is the theoretical calculation method. It is mainly based on the mathematical model of the system to determine the controller parameters through theoretical calculations. The calculation data obtained by this method may not be directly used but must be adjusted and modified through actual engineering.

The second is the engineering setting method

the second is the engineering setting method, which mainly depends on engineering experience and is directly performed in the test of the control system. The method is simple and easy to master. The engineering setting methods of PID controller parameters mainly include critical ratio method, response curve method and attenuation method. Each of these methods has its own characteristics. The common point is to pass the test and then set the controller parameters according to the engineering experience formula. However, no matter which method is adopted, the controller parameters need to be adjusted and improved in actual operation. The method for setting the PID controller parameters using this method is as follows: (1) first select a sufficiently short sampling period to allow the system to work; (2) only add the proportional control link until the system responds to the input step response with critical oscillation Note down the proportional amplification factor and critical oscillation period at this time; (3) Under certain control degree, calculate the parameters of the PID controller by the formula [7].In order to tune the PID controller, some parameter is important should be based on Table (1)[9].

Table (1): PID Controller Parameters

NO	Parameter	Definition
1	Rise Time	the amount of time the system takes to go from 10% to 90% of the steady-state, or final value
2	Percent Overshoot	the amount that the process variable overshoots the final value, expressed as a percentage of the final value
3	Settling time	the time required for the process variable to settle to within a certain percentage (commonly 5%) of the final value.
4	Steady-State Error	the final difference between the process variable and set point

Most PID controllers are tuned on-site due to machine and process variations. The theoretical calculations for an initial setting of PID parameters can be bypassed using a few tuning rules. By name, there are two most common methods to determine and tune PID. One is the Ziegler-Nichols method and the other is Cohen Coon method [23]. The Ziegler-Nichols method is the most widely used because it's quite simple to calculate and the Cohen Coon method involves a bit more calculations, but it is still easy to use, and it is suited to a wide array of processes. Both methods work by generating a response curve from a step input in user control output. Some parameter read from this curve and then using calculations to determine the P, I and D constants with the following adjustments.

- **Adjustment of the proportionality factor [3]**

The adjustment range of the proportional coefficient P is generally: 0.1--100. If the gain value is 0.1, the output of the PID regulator changes to a deviation value of one-tenth. If the gain value is taken as 100, the output of the PID regulator changes by a hundred times the deviation value. The larger the value, the greater the gain effect produced by the ratio. During the initial adjustment, choose a smaller value, and then slowly increase it until the system fluctuation is small enough, and afterwards adjust the integral or differential coefficient. Too large P-value will cause the system to be unstable and continue to oscillate; too small P-value will make the system unresponsive. The appropriate value should make the system have enough sensitivity but not be too sensitive. The delay of a certain time depends on the integration time [8].

- **Adjustment of integration coefficient**

The integration time constant is defined as the time that the deviation causes the output to increase. The integration time is set to 1 second, and the time required for the output to change by 100% is 1 second. During the initial adjustment, set the integration time longer, and then slowly decrease until the system is stable [8].

- **Adjustment of differential coefficient**

The differential value is the rate of change of the deviation value. For example, if the input deviation value changes linearly, a constant adjustment value is superimposed on the regulator output side. Most control systems do not need to adjust the derivative time. Because only the system with time lag needs to add this parameter. If one adds this parameter to the system, the control of the system will be affected. If the ideal control requirements are still not received through the adjustment of the proportional and integral parameters, the differential time can be adjusted. Set this coefficient small during initial tuning and then, increase it slowly until the system is stable [8]. For the Ziegler-Nichols method as shown in figure (9). The main tuning parameters of PID are Rise time, Settling time, Steady-state and overshoot via the adjustment of proportionality factor, integration coefficient and the differential coefficient.

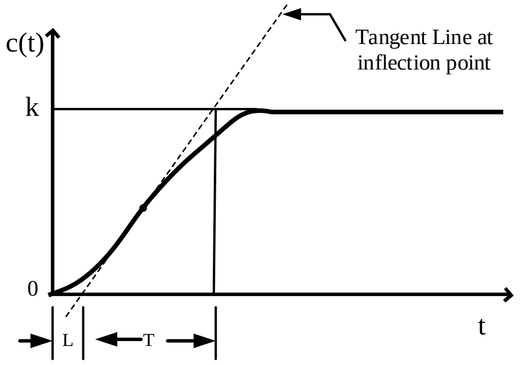

Figure 9: Reference Curve

As it is shown in figure 9 reference curve, the S-shaped reaction curve can be designated by two constants, delay time L and time constant T, which are determined by drawing a tangent line at the inflection point of the curve and finding the intersections of the tangent line with the time axis and the steady-state level line. Then, the tuning method for controlling should be as Table (2). This is one of the methods to do the trick. [10]

Table 2: The Ziegler method

NO	Type of Controller	Kp	Ti	Td
1	P	T/L	Infinity	0
2	PI	0.9T/L	L/0.3	0
3	PID	1.2T/L	2L	0.5L

According to the algorithms used for the PID controllers, the most common way to tune the variables is:

- Start with a low proportional and no integral or derivative.
- Double the proportional until it begins to oscillate, then halve it.
- Start implementing Derivative until it becomes flat line with the steady step.
- Slowly implement the integrals until it becomes stable.

Assuming the steady step is like this, that the rise time is from 0 to 1 and then goes flat. Then accepted range of rising time can be from 0 to 1.2 considering there is overshoot. The settling time must be within 5% range of the final value for the system to be optimum. And the aim has to be that the steady-state error becomes zero or very close to zero depending on the algorithm used.

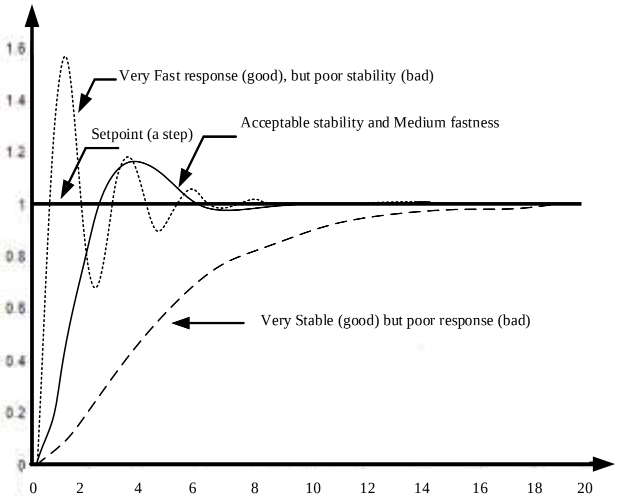

Figure 10: Sample PID Curve

As it shows in figure (10) the middle curve is the most acceptable form of the curve as it has acceptable stability and medium fastness hence a good compromise for the whole system. Based on the main aim of this paper on AGV robot platform, PID tuning is very important, such as, Each AGV or Machine has its own set of function, hence, in order to accomplish the exact set of workload more efficiently one needs to actually tune the PID parameters accordingly so that there cannot be an intolerable amount of energy loss, inefficiency rate, lag, lack of robustness etc. The parameter before and after PID Tune are shown in Table (3).

Table 3: the PID Parameter and performance

No	Parameters	Before Tuning	After Tuning [Ziegler Nielsen Method]
1	Rise Time	Variable	Decrease
2	Overshoot	Exists	Reduced
3	Settling Time	Slow	Reduced
4	Steady State Error	Low Error	Little to No error

Then, based on the PID parameter, the effects of increasing each controller parameters K_p, K_i, and K_d can be summarized as shown in Table (4): [10]

Table 4: the PID Parameter and performance

No	Response	Rise Time	Overshoot	Settling Time	Steady State Error
1	Kp	Decrease	Increase	Minor Change	Decrease
2	Ki	Decrease	Increase	Increase	Eliminate
3	Kd	Minor Change	Decrease	Decrease	Minor Change

3- *AGV PID Tune method*

Hauling Zhang et al [13] in their paper have aimed at AGV motion model of two-wheeled differential drive control modes. They have divided this mode into two other modes. They are defined as double closed-loop control based on Lyapunov direct method and sliding mode control technology and speed control based on the PID method through hierarchical control thought. The double closed-loop control structure has two rings or loops and they investigated that the virtual speed vector output by the external controller is the expected value of the internal ring hence, it establishes a relationship between the kinematics and dynamics of the whole system directly.

In their research, they did some test tracking under MATLAB/SIMULINK environment. Their simulation result verifies that AGV can trace the given geometric path more rapidly and correctly compared to other systems out there. They used PID here to have different control modes for their AGV tuning, which are mentioned before as hierarchical control and Lyapunov direct method. Having different modes on PID is the novel thing they have achieved. Jorge Villagra et al [14] in their research have shown a detailed comparison between different control methods for AGV robust path tracking where they ensured low jerk variations when docking AGVs in industrial environments. Their proposed control system focused on both robustness and performance at one side and easy configuration capabilities of the controller on the other. Two control techniques namely, fuzzy and vector pursuit and a data-driven model for feedback control combined with differential flatness control were compared together using exhaustive Monte-Carlo Simulation. Their research simulations concluded that a model-based controller has excellent tracking quality under a high degree of uncertainty while a non-model-based controller (fuzzy and vector pursuit) has an acceptable level of transportability regardless of high amplitude. They added that having an Intelligent PID (I-PID) controller compensates for skidding, slipping and actuators dynamics without the need of physical parameters.

Young Jin-Lee et al [15] in their research have designed an experimental AGV system for automated container terminal with intelligent PID (I-PID) controllers. They aimed for a more effective system using the idea of the biological immune system which is cell-mediated immunity. This system intelligently adjusts its parameters just like the self-regulating mechanism of the immune system. The researchers used such type of PID to enhance control and let the AGV learn as it goes. The parameters for the designed controller have been optimized using HIA or the humoral immune algorithm. The proposed system with this new PID controller was put on par with existing classical PID and NNPID systems respectively and was thoroughly compared with each other using various constant loads having both maximum displacement errors and average displacement errors. The result showed a 17% and 16% and, a 27% and 20% improvement with the systems respectively. It was also concluded that the proposed controller reduces the energy required for controlling the steering and speed settling. The novel thing about this is the usage of a self-regulating hence self-learning mechanism in PID. Jin-Woo Lee et al [16] experimented in their paper for AGV Steering Control and Identification using Vision from a color CCD camera. In their designed AGV they set up the camera on the front and grabbed the 3D image of the designated path of the vehicle. It was then converted into a 2D image from which the AGV processes its driving conditions. Using the filtering process, they drew out the ratio of the color of the path which is converted into a simple X-Y Co-ordinate system and through that the steering angle is calculated. This whole process takes about 20 frames/sec and thus the driving state is recognized and is sent to the AGV's microprocessor. Neural network identifier has been used to eliminate the time delay issue from the vision system. Hence, the modified PID controller has been designed using the neural network algorithm and applied to the steering control of the AGV. The conclusion was made that the result of this attempt did not require any consideration of line detection, labelling algorithm etc rather only the vision sensor was enough to ensure faster guideline detection using only image processing. For this particular research, the researchers used PID but only to work with the help of visual identification. Having a different sense to work with PID is a new idea to reach for this field. W.S. Wijesoma et al [17] in their research have portrayed stable fuzzy controllers' designs for an AGV. In their paper, they have stated 3 controllers namely, Sliding Mode Controllers (SMCs), Fuzzy SMCs, and Fuzzy PD controllers. Experiments on all 3 were carried out by giving each controller a steering angle profile having a trapezoidal steer angle starting from zero. Results showed that all the three controllers' performance were relatively similar to each other with nothing much of a difference other than the fact that fuzzy controller had slightly fewer tracking errors meaning higher tracking accuracy. The paper concludes the same and adds that it gives more degrees of freedom in performance tuning while using SMCs and inclusion of heuristic control knowledge in simple state variables, whereas using fuzzy control permits treatment of linear combinations of state variables. Laurens Jacobs et al [18] in their research have proposed an LPV (linear parameter varying) control design strategy for trajectory tracking using a varying linear parameter control i.e. a non-linear kinematic control. They approximated the tracking problem for the nonlinear model by a tracking problem for a linear parameter-varying model. Their controller design method had a closed-loop characteristic. The research shows the pristine usage of varying linear control over the closed-loop designed PID controller. The control software of the robot was programmed in an OROCOS environment which could communicate with the sensors and motors through Ether CAT protocol at a rate of 100HZ. They used LCToolbox from MATLAB to solve the control problem. They validated this controller on a prototype of an autonomous mobile platform in a greenhouse. The results show that the tracking performance is centimeter precise thus achieved a satisfying precision.

Yu Dianyong el al [19] in their paper has adopted a self-adjusting fuzzy control method that can make AGV trace the reference path at a definite speed but at a higher precision and the speed of the vehicle tend to the tangent direction of its trajectory. Their designed guideway of the AGV used a photoelectric guideway and the usage of such a mechanism with PID controller is unhackneyed. In their simulation, they used an AGV with the speed of 0.3m/s and, the results showed higher precision and rapid response from the system. The experimental results were much closed to the actual simulation also. Even when having the bigger deviations of the parameters the vehicle was able to return to its original position in a shorter time. Lastly, the researchers have concluded that their method has a higher control precision and better dynamic performance when it comes to controlling AGV. Because, they do this through a fuzzy controller. They further conclude that using photoelectric guideway has better advantages of easy construction and easy assigning of variables.

Priyam Parikh et al [20] have researched on their paper about implementing fuzzy logic controller and PID controller to a DC Motor to achieve constant RPM. In their project, they have designed an AGV in which they implemented a PID controller technique using the Ziegler Nichols algorithm and Mamdani technique for the fuzzy logic controller. Then, they programmed and managed delays using a microcontroller and applied the AGV motor to it via Microcontroller. Finally, they have interfaced a MATLAB Simulink. Their proposed system after experimentation concluded the result that the error, overshot and rise time in PID controller is much lesser for the fuzzy logic controller. The whole system is more stable and more accurate due to the fuzzy logic controller. Finally, the researchers conclude alongside their experiment's result that using their method of implementing fuzzy logic controller and PID controller lets the AGV achieve constant speed in 0.8 seconds with only 1% overshoot and they state that in the future using ANFIS controller which stands for Adaptive Neuro-Fuzzy Inference System (the combination of fuzzy logic controller and neural network system), the small oscillations in the system response can also be reduced.Hong-Jie tang et al [21] stated in their paper that their proposed system based on their designed PID controller has good tracking performance in a straight line as well as it as strong adaptability and high robustness while tracking circular path. In their paper, they used two DC brushless motors and hence their AGV goes with two differential speeds. The vehicle has a magnetic navigation sensor which both detects declination or inclination of the relative tape as well as the tape as its directed path. They used MATLAB Simulink platform to simulate the mathematical model of the design. Their PID control algorithm is an incremental PID control expression which does not require accumulation while calculation; the incrementation corresponds to the change of the position of the actuator and this is the only value outputted by the computer hence the influence of error when occurred is small. The algorithm with collaboration with the sensor only calculates the deviation from the path which is the tape. The results showed that by using magnetic navigation PID control overshoot is small and this control method can effectively correct AGV deviation and track the given path.K.R.S. Kodagoda et al [22] in their paper have proposed a control structure for uncoupled lateral and longitudinal control for an AGV. They achieved lateral control using fuzzy controllers and longitudinal control using fuzzy drive controller and fuzzy braking controller. A supervisory controller which implemented the heuristics that the AGV will only break if and only if the actual speed was greater the requested speed was used as the switch between the different controller of the longitudinal control. Their experiment shows that the fuzzy logic controller schemes outperform the traditional PID schemes when it comes to tracking accuracy and steady-state errors. Furthermore, the results showed that the fuzzy logic controllers are robust to load changes, coupling effects etc. When coupled DC motor to the designed controller showed smooth speed tracking performance with no jerk.

4- *Conclusion*

To control the systems, generally different combinations of three terms of P, I, and D are used which intended to the controller like: P (Occasionally used), PI (Most frequently used) PD (rare but can be useful for controlling in some applications like servomotors etc) and PID. So, between them, the PID due to its better ability is of more demand. Even some researcher believes that using the PID under different control schemes to ease their work and get the desired result. The mentioned controller has some merit and demerits and applications which are shown in Table (5) briefly.

Table (5): The PI, PD and PID Controller

NO	Controller type	Advantages	Disadvantages	Application
1	PI	Zero steady state error, Stability and Maximum peak overshoot is better than Integral only Controller	We cannot use PI controller for slow moving Process variables	Majority of the speed control applications use PI control action. Eg. Speed control of motors, generators, turbines etc
2	PD	Stability increased, Maximum peak overshoot decreased, Settling time decreases	Steady state error is not zero, cannot be used for fast moving process variables like flow, pressure, highly affected by external noise. A PD controller is analogous to a HPF along with amplifier. This it amplifies high freq noise if present.	PD controllers are most widely used in temp control applications.
3	PID	steady state error is zero, moderate peak overshoot, moderate stability, can be used for controlling both fast and slow process variables.	cost is high, Complexity and tuning, design complexity	for almost every application by proper tuning

AGV robots as the controlling system need to have a controlling loop to follow its task and mission in various goals. The comparison between PID and aim in different researchers are shown in Table (6).

Table (6): Comparison Between Existing PID Controllers

No.	Specifications	Fuzzy Controller	i-PID Controller	Two Wheel Differential Controller	Other Controllers based on novel algorithms
1	Path Tracking	Accurate	High Accuracy	Rapid Tracking of geometry	Satisfying precision
2	Jerk Management	Low to no Jerk	x	x	x
3	Uncertainty Tolerance	High	Based on reference	Not Good	Depends on the algorithm
4	Self-Adjustment	Good	Very Good	Can be better	Depends on the algorithm
5	Robustness	Better for load changes	Very good	Not good	Very Good with incremental algorithm
6	External Data required	No	No	Yes	Not always
7	Overshoot	Small	x	x	Small
8	Steady-State Error	Fewer Errors	Depends on Parameter Changes	x	Outperforms traditional PID Controllers
9	Speed Tracking	Definite Speed with higher precision	Good with energy saving	Very Smooth with differential speeds	Smooth

As the Table (6) shows, the reviews on previous papers show, most of the researchers are used some form of PID with some form of tuning method based on their system requirements. Huaqiang Zhang et al [13] have used PID to have differential drive control and he used a tuning method based on Lyapunov Direct Method of control to achieve their goal. Jorge Villagra et al [14] have used PID for their AGV's robust path tracking. They used an intelligent PID controller alongside a fuzzy controller which is a novel way of implementation – the combination of two PID controllers. Young

Jin-Lee et al [15] takes it to a step further because they use intelligent PID controllers and have tuned a PID algorithm based on the human immune system called the humoral immune algorithm. While till now all the researchers have used some form of PID tuning, the next group of researchers namely, Jin-Woo Lee et al [16] have not used any major form of PID tuning. Rather they used visual images and a neural network does the trick, which is a very novel thing. Then, again Priyam Parikh et al [20] have researched with fuzzy logic controller and PID controller. But they have used the traditional Ziegler Nichols algorithm to tune their fuzzy PID, so nothing new is presented here in terms of tuning other than implementation. Hong-Jie tang et al [21] have used a PID tuned with incremental PID control algorithm which is also relatively new. So, most of the researchers who have been mentioned here have done something novel to tune their PID controller in their systems. The most noteworthy novel things here are using a combination of two or more PID controllers, using different control techniques and tuning methods for each of the controllers and then combining them, using visual aid and intelligent control network to reduce controller tuning, using intelligent PID controllers and finally even when using traditional tuning method, they have implemented them in a non-traditional way like in a fuzzy logic controller. This work can be implemented on various robotic applications [24-28] especially odor tracking [29-30] and pipe inspection robot [31-34]. The future work will be focus on effect of various PID tune on AGV dynamic model.

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