Alternative Feedback Control Methods To Standard PID

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Feedback controllers stabilize a system through one or several feedback parameters. This paper focused on the classical PID controller, used both throughout academia and industry. It is therefore useful to understand how to optimize the PID controllers for use under dynamic conditions, where spikes are readily encountered. A line following robot is considered under conditions of widely changing UV light, and speeds of 0 to 8 m/s, and demonstrates the need for autonomous, dynamic recalibration. This paper contrasts standard Ziegler Nichols PID tuning with supplementary tuning methods, including tuning by fuzzy logic, and fractional order parameter tuning. This paper also loosely considers H2 and H Infinity Optimization, and Particle Swarm Optimization (PSO), which are operable on non-PID controllers and are therefore only loosley being considered for the purposes of this paper. The results suggest that fractional order, fuzzy logic PIDs (FOF-PIDs) are the best for application in academia and the small electronics industry. FOF-PID performed at 88 percent higher efficiency than Zielger Nichols method on its own, and FPID performed at 71.2 percent higher efficiency than Ziegler Nichols method.

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I. INTRODUCTION

Determining reliable feedback controller parameters is hugely important to the electronics and automation industry and greatly used by students and instructors throughout academia. There are also extensive studies completed in this area. Standard proportional-integral-derivative (PID) controllers operate by convolving an input signal by an appropriate transfer function so to stabilize the system. This requires adequate stabilizing parameters, one for each error term, including immediate errors (proportional term), historic errors (integral term), and anticipated errors (derivative term). Supplementary tuning methods include fuzzy PIDs (FPIDs), fractional order PIDs (FO-PIDs), or a combination of both (FOF-PIDs). FPIDs, FO-PIDs, and FOF-PIDs build upon standard PID tuning so to more reliably maintain conditions in changing environments [2,5,8,9,16]. Alternative feedback controller methods include PSO method, and H2/H Infinity Optimization, which were loosely considered for the purposes of this paper.

Understanding optimal PID tuning design affects academia, both students and instructors, and companies that rely on PID controllers. Companies can benefit from better discerning appropriate tuning methods for PID controllers by reducing, if not eliminating superfluous reconstruction and fail-safe resources that cost the company and impact the environment. Companies can also benefit from reduced training and time otherwise required for tuning and other troubleshooting procedures. Students and instructors can benefit from better discerning appropriate tuning methods for PID controllers by recentring their attention from reconstructing, to instead using this information as a tool to challenge other areas of the curriculum. Immediate benefits therefore include empowered design for existing technologies, heightening performance and reducing superfluous resources. Long term benefits include discovering even better tuning strategies through ongoing application and research.

II. EXPERIMENT

The experiment was constructed from an RC drift car, illustrated in FIG 1, with a pre-accompanied drive and steering servo, and operating speed of 0 to 8 m/s. The car included two IR LED sensor arrays and an ultrasonic sensor attached at its front end, both wired to a Raspberry Pi microcontroller fixed in the interior top side of the car and programmed in Python. The microcontroller processed the information from these sensors to direct where the car should move, or whether it should stop. The car achieved this through ultrasonic detection of nearby walls, and when passing a count threshold off the line. In addition to ultrasonic and IR sensors, the car incorporated Bluetooth detection of nearby runners. This would be to match speed, and give the car its primary function being to set the pace for a race. The Zeigler-Nichols method was used to determine the parameters of the PID control, and a feedback control algorithm.

III. RESULTS

The Ziegler Nichols method was inefficient on its own as demonstrated from FIG 2. This method requires setting the derivative and integral terms to zero, and tuning the proportional term until a constant period is observed by the system. When a constant period is found for the P controller, called ultimate period, the associated proportional term, called the ultimate gain, is used to solve the new integral, and derivative terms. FIG 2 illustrates

FIG. 1. The line following robot. It is built of an RC car, with the Raspberry Pi under the top plate. A 5V battery is on top of the car, and directly connects to, and powers the Raspberry Pi. The ultrasonic sensors are attached on the front of the bumbers, and the IR sensors are under the bumpers.

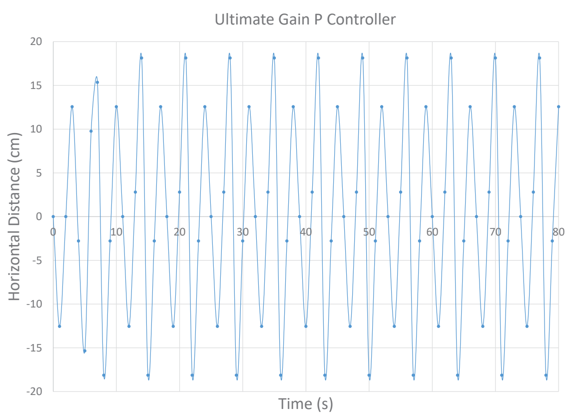

FIG. 2. The figure represents the finished P controller. Zero horizontal distance represents the line the RC car is following. The oscillations of the car nearly reach 20 cm in both directions. The ultimate period is seen as the repeating period, approximately 4 seconds in duration.

TABLE I. Setting the initial angle to 1 degree off the line. The negative and positive values represent directions in the y axis of FIG 2. The table illustrates the first two periods, each 4 seconds in duration.

Ultimate Gain PID Controller			
Time (s)	PID Turn	Angle (d)	Vx (cm/s)
0	0	1	0
1	-12.555	1	3.490481
2	0	-0.8	-2.79244
3	12.555	-0.8	-2.79244
4	-2.79	1	3.490481
5	-15.345	0.6	2.094357
6	9.765	-1.6	-5.58433
7	15.345	-0.2	-0.69813
8	-18.135	2	6.979899

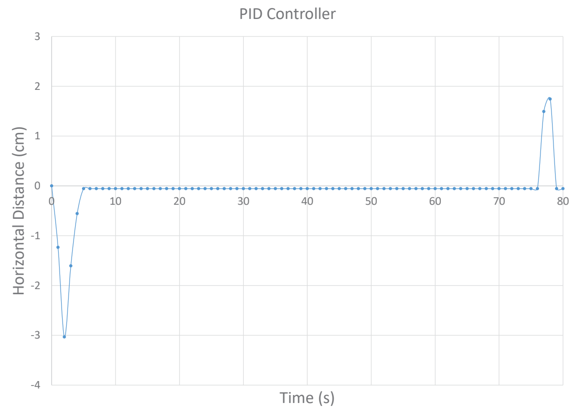

FIG. 3. The figure represents the finished PID controller. Zero horizontal distance represents the line the RC car is following. The car reaches 3 cm in one direction within the first 5 seconds before reaching steady state and remains on the line thereafter.

TABLE II. Setting the initial angle to 1 degree off the line. The negative and positive values represent directions in the y axis of FIG 3. The table illustrates the first two periods, each 4 seconds in duration.

PID Controller			
Time (s)	PID Turn	Angle (d)	Vx (cm/s)
0	0	1	0
1	-1.233	1	3.490481
2	-3.033	0.880889	3.074761
3	-1.605	0.587892	2.052096
4	-0.555	0.432845	1.5109
5	-0.055	0.37923	1.323754
6	-0.055	0.373917	1.305208
7	-0.055	0.368604	1.286662
8	-0.055	0.363291	1.268116

a horizontal distance of 20 cm off the life, which put the car at risk of damage. This was also the best displacement distance for the P controller relative to other tuning attempts, further suggesting the inefficiency of the stand alone Ziegler Nichols tuning method. Fuzzy logic was intuitively applied, setting boundaries on how long the car could remain off the line as well as recalibrating the IR sensor threshold to account for changing sunlight. This method took over a week and was limited to 2 m/s speeds due to the work required to determine unique parameters for each speed. This prevented the car from remaining on the line during automatic speed adjustments that were prompted by the Bluetooth sensor. The car was therefore put at even greater risks of damage when exposed to changes in speed or sunlight conditions, which made it unable to perform its desired purpose. The final PID results are given in Figure 3. Different tuning methods were considered to supplement, if not replace the existing design.

IV. EVALUATION BY FUZZY LOGC AND FOF-PID

Fuzzy PID method was considered for its ability to uniquely evaluate control system parameters. The fuzzy method uses fuzzy logic to adapt the system, exchanging absolute truth and false statements with "partially true" and "partially false" statements [2,5,8,9]. This can be achieved by computational methods, to limit the distance the car travels off the line, or to adjust tunable parameters in accordance to changes in speed or sunlight exposure. This resulted in a more responsive PID controller right off the bat. More experimentation is needed to verify changing parameters, although we can assume from induction the feasibility.

Fractional order PIDs are inclusive to additional tunable parameters. The most common is the integral and derivative parameters consideration, as given in the eqquation (1) below. These additional parameters are better for dynamic environments and maintain smooth operation by dampening these terms [16]. We can see this from FIG 4 and FIG 5. FOF-PID controller tuning was the most accurate right off the bat. More experimentation is needed to verify how FOF-PID responds to changing speed and sunlight exposure perameters, although like in the fuzzy PID we can assume from induction the feasibility [2]. Understanding fuzzy PID controllers, likely progression for building the FOF-PID controller is to start with all parameters, and then incorporating fuzzy logic for dynamic tuning [2].

$$u(k) = Ke(k) + K_i D^{-\lambda} e(k) + K_d D^{\mu} e(k)$$

V. EVALUATION BY H2/H INFINITY OPTIMIZATION AND PARTICLE SWARM OPTIMIZATION

H2/H Infinity Optimization are obsolete in cases where efficiency is the goal. Both methods require augmenting the PID into vector space and solving the linear matrix inequality for non-trivial solutions [6]. H2 method constrains the relation to reduce the average error and H Infinity reduces the maximum error [6]. In application, H2 Optimization ensures that the car will stay close to the line, while H Infinity Optimization ensures the car responds well to spiked errors. While both methods are reliable, they omit standard PID tuning and therefore will require the additional training resources otherwise not as necessary for the better understood and implemented PID controller.

PSO method can be integrated with our FOF-PID controller, although requires further mathematical analysis.

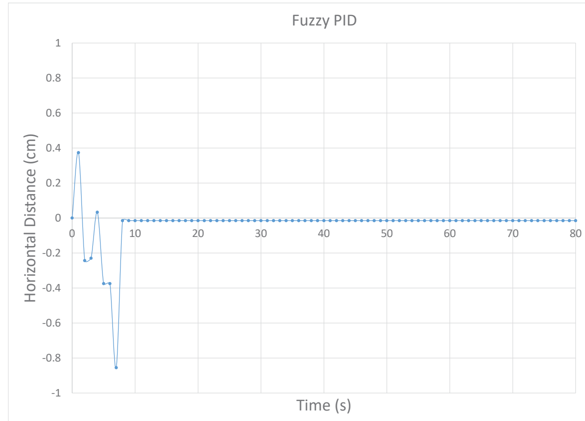

FIG. 4. The figure represents the finished FPID controller. Zero horizontal distance represents the line the RC car is following. The car reaches 0.885 cm in one direction within the first 10 seconds before reaching steady state and remains on the line thereafter.

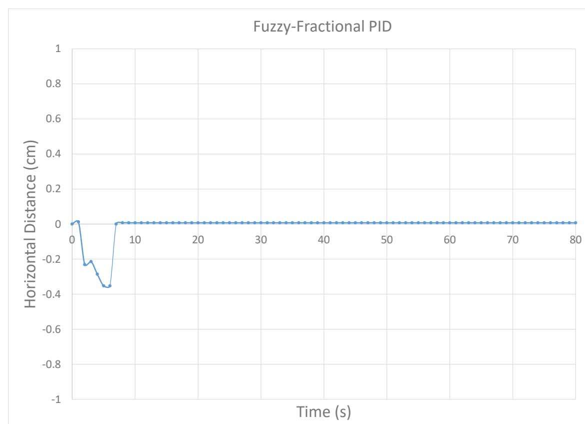

FIG. 5. The figure represents the finished FOF-PID controller. Zero horizontal distance represents the line the RC car is following. The car reaches 0.353 cm in one direction within the first 10 seconds before reaching steady state and remains on the line thereafter.

Like Monte Carlo method, PSO assigns weighting factors to many plausible solutions until the true solution is collectively discovered [3,9,11]. Unlike Monte Carlo, PSO method bases finding the solution on the intelligent operation of its particles. This makes particle swarm superior in advanced applications where continuous progression is valued above the efficiency of discrete progression. For this experiment, PSO is less efficient and therefore lower priority than discrete algorithms. An alternative to PSO method is nonlinear fuzzy PIDs, which would require less training resources and relatable performance.

VI. DISCUSSION

FOF-PID controllers demonstrate more reliable results than the Ziegler Nichols method on its own. Although intuitively considered in the initial design by limiting the maximum time spent off the line, and sensor recalibration procedures, the method can be expanded to include the feature of autonomous tunable parameters. We can intuitively note this as a viable solution for the car to serve its primary purpose. FOF-PID controller was demonstrated to be the most accurate, and nonlinear fuzzy logic (performing as a simplified PSO method) could further ensure the accuracy of the car in cases of dynamic environments, although we won't get into nonlinear fuzzy logic as it requires deeper mathematical analysis than what is considered necessary for the purpose of this experiment. Dynamic environments can include both widely and quickly changing lighting conditions on the sensors, and speed conditions prompted by a dynamic race.

From our data, its noted that FOF-PID also tuned faster than the FPID method. This supports FOF-PID as being more reliable in the troubleshooting phase than alternative models, reducing the likelihood of damage to our car and likelihood of extensive troubleshooting time. The figures show small differences between the FPID and FOF-PID models, suggesting that FPID is relatively sufficient on its own under strict time constraints. FOF-PID may require considerably more time than other methods considering the added parameters. The FOF-PID is however superior for accuracy as supported by the findings. Although no mathematical analysis was performed that involves PSO or H2/H Infinity Optimization methods, the available literature marks these methods as diverging away from standard PID control. They are therefore inefficient for the purpose of this experiment and paper.

VII. CONCLUSIONS AND SUMMARY

Ziegler Nichols method was demonstrated to be inefficient in application to a line following car traveling at 0-8 m/s. This was because of the risky tuning requirements associated to finding the ultimate gain. The FPID and FOF-PID tuning methods were demonstrated as being superior to the stand alone Ziegler Nichols method, supplementing the stand alone method with an autonomous tuning feature that was applied to the PID parameters, and thought also applicable to the autonomous tuning of the IR sensor. The results demonstrate an 88 percent decrease in the initial horizontal travel fluctuations of the car in the case of FOF-PID tuning method, and 71.2 percent decrease in the initial horizontal travel fluctuations in the case of the FPID tuning method. This paper doesnt quantitatively consider the practical impacts of using H2/H Infinity Optimization methods, or PSO or nonlinear FPID methods and this is suggested for further research.

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