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# AUTOMATIC PID PARAMETER TUNING BASED ON UNFALSIFIED CONTROL

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**Abstract.** Traditional robust control, or adaptive control, is based on accurate models. They can only control the systems with sufficiently small or constant uncertainty. To overcome the shortcoming, the paper proposes an unfalsified control based on data driving, which is a type of model-free adaptive control. The method is data-driven and thus does not rely on the system model. The designed controller is simple and highly adaptable to online application. In this paper, the basic theory of unfalsified control is introduced and applied to the real-time tuning and adaptation of the PID controller parameters. Simulation is also conducted when there is disturbance with the system. The result shows that the algorithm is actually fairly robust to noise and perturbation. The feasibility and effectiveness of this algorithm are also proved by the simulation results.

**Keywords:** unfalsified control; PID; data driving; model-free control.

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**Problem statement.** The mathematical model of the controlled system is the basis of the application of modern control theory. Yet, when the controlled object cannot be accurately modeled or the model uncertainty is beyond upper threshold, it is difficult to achieve the desired control objectives with a single controller. In order to solve these problems, Michael. G. Safonov proposed the unfalsified control theory based on simulated human decision-making [1]. It is a control strategy different from multi-mode control, implying that different controllers are applied to the controlled object at different working intervals, and the optimal controller is chosen based on the information of open-loop or closed-loop systems. The traditional methods of theoretical analysis based on transfer function are Root-locus Method and Nyquist Theory, but they are not suitable for unfalsified control, being a mathematical screening method without model [2].

This paper presents an unfalsified control method based on data [3]. It introduces an adaptive method of PID parameters adjustment without the system model and emulates the system with the algorithm of the unfalsified control method.

**Basic material.**

***1. Theory of unfalsified control***

The basic idea of unfalsified control is as follows. At first, a set of controller parameters is built that satisfies the performance index based on the measured data. When the control method used in the system is denied based on the new data measured in the current circuit, a new controller is switched automatically. When all the control methods in the control set comply with the measured data and can meet the performance index, an optimization algorithm is designed to reduce the feasible region of the appropriate controller.

Switching control methods are divided into indirect switching and direct switching, namely, multiple model control and multiple controller [4]. Unfalsified control is a direct switching method based on a multiple controller. Compared with the general switching control method, unfalsified control acts on the system before close-loop feedback and can switch or choose the controller based on the cost function built by the measured data of the object; it provides a good transient response.

The structural block diagram of a basic unfalsified control system is shown in Fig. 1.

In Fig.1, $r$ designates the input signal, $N$ stands for the number of elements in the controller set, and $x_{oi}(i = 1, 2, \ldots, N)$ stands for the initial state of the controller. Thus, $x_{op}$ is the initial state of the object, $u_p$ is the input of the controlled device, and $y_p$ is the output of the controlled device. Finally, $d$ stands for interference, and $n$ stands for noise. Supervision organization is used to complete unfalsified control of the controller. The specific process is to calculate the performance index based on the real-time input and output data measured in the system and select the controller that meets static and dynamic performance to force the system; the falsified controller that does not fit is abandoned.

Data set, controller set and performance index are the most important elements in the unfalsified control theory. Whether the controller is unfalsified can be judged by intersection of the two sets. In order to explain thy essence of unfalsified control, let us define the following notions.

*Definition 1:* Falsified controller [5]. When the controller is placed in the control loop, its compliance with the performance index can be judged by the input and output data measured in the system. If the controller is unfalsified, it can meet the performance index of the system.

*Definition 2:* Measured data set is described as follows:

$$P_{data} = \{(r, y, u) \in R{\times}Y{\times}U \,|\, y = P_u\}. \quad (1)$$

Controller set:

$$K = \{(r, y, u) \in R{\times}Y{\times}U \,|\, u = K[ry]^T\}. \quad (2)$$

Performance index is expressed as follows:

$$T_{spec} = \{(r, y, u) \in R{\times}Y{\times}U \,\|\, J(r, y, u) \le 0\}. \quad (3)$$

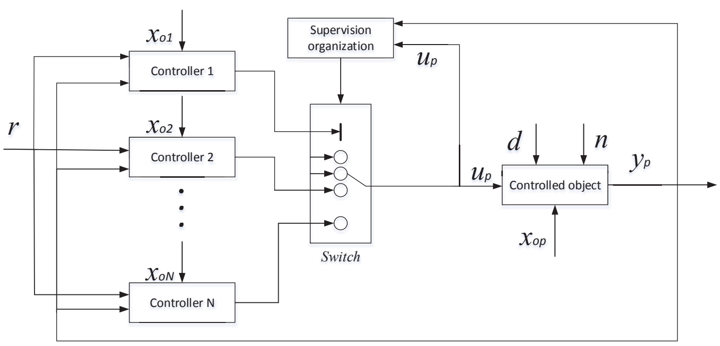


**Fig. 1.** Configuration of an unfalsified control system

Whether the controller is falsified or unfalsified can be judged by calculating the intersection of these sets.

*Theorem 1.* The necessary condition of the controller $K$ proved to be unfalsified is if and only if one of the measured data $P_{data}$ satisfies $(r_0, y_0, u_0) \in P_{data} \cap K$, in other words, at least one array $(u_1, y_1)$ satisfies the following formula:

$$(r_0, y_1, u_1) \in P_{data} \cap K \cap T_{spec} \quad (4)$$

When the open- or close-loop data from other activated controller $K_i$ is used for the performance of an alternative controller in the process of estimating, fictitious reference signal $\tilde{r}(K_i, u_p, y_p)$ plays an important role in the system [6]. This is caused by the use of fictitious reference signal, which makes the controller switching timely and easy to handle. Fictitious reference signal is defined as follows.

*Definition 3.* $\tilde{r}_i$ for fictitious reference signal.

Given the object data $(u, y)$ and an alternative controller $K_i$, the fictitious reference signal is defined as follows. During data acquisition, controller is in the feedback circuit, and fictitious reference signal generates the same signal $(u, y)$. As long as the controller is reversible, the fictitious reference signal $\tilde{r}_i = K_i^{-1}(u)+y$ of controller $K_i$ can be calculated with the help of the measured data $(u, y)$.

## 2. Adaptive PID algorithm based on unfalsified theory

PID control is easy to implement and adjust with its own characteristics; it is widely used both in industry control and aviation [7]. Many methods have found practical application in tuning of the parameters of PID control, but with the increased complexity of the system, traditional ways to achieve parameter adjustment are becoming more difficult to implement. This paper presents a method for the PID parameter tuning only with input and output data, without the object model. The specific control structure is shown in Fig. 2.

A self-adapting data-driven PID algorithm is used in order to autoselect three PID control parameters, $k_P$, $k_I$, and $k_D$. A data-driven algorithm is a kind of recursive operation based on unfalsified control theory [8]. The data measured in the system is used in control progress in order to judge whether the PID parameter can meet the command of systems, applying this method for self regulation.

A PID controller with approximate differential parts is shown in formula 5:

$$u = \left(k_P + \frac{k_I}{s}\right)(r - y) - \frac{sk_D}{\varepsilon s+1} y. \quad (5)$$

The standard PID controller gain $k_P > 0$, $k_I > 0$, $k_D > 0$ is a causal relationship reversible [9]. For each controller $K_i$, there exists a unique virtual reference signal $\tilde{r}_i$ based on the measured data $u(t)$ and $y(t)$. As shown in formula 6, $\tilde{r}_i$ can be calculated based on the measured array $(u, y)$. There, $K_i = [k_{Pi}, k_{Ii}, k_{Di}]$ is a subset in $R^{n\times3}$, $R^{n\times3}$ is a parameter set of the controller, and n stands for for any real number [10].

$$\tilde{r}_i = y + \frac{s}{sk_{Pi}+k_{Ii}}\left(u + \frac{sk_{Di}}{\varepsilon s+1}\right). \quad (6)$$

For any moment of time τ, the relation between $T_{spec}$ and a set of three dimensional arrays can be described with the integral inequality shown in formula 7:

$$J(t) \le -\rho + \\ + \int_0^t T_{spec}\left(\tilde{r}_i(t), y(t), u(t)\right)dt \le 0, \forall t \in [0, \tau]. \quad (7)$$

where $\rho \ge 0$, $u(t)$, $y(t)$, $t \in [0, \tau]$ are the measured object data, $\tilde{r}_i(t)$ stands for the virtual reference signal of the controller $K_i$, and $T_{spec}(\tilde{r}_i(t), y(t), u(t))$ stands for the performance index [11]. Performance index designed in this paper is described as follows:

$$T_{spec}(\tilde{r}_i(t), y(t), u(t)) = |w_1 * (y - \tilde{r})|^2 + |w_2 * u|^2 - |\tilde{r}|^2 - \rho^2. \quad (8)$$

where $w_1$ and $w_2$ are designed as weight function, and $*$ stands for the convolution operator.

Upgrading formula 1, the necessary condition for the measured data $u(t)$, $y(t)$ proved to be unfalsified of the $i$-th candidate PID controller $K_i$ is shown in formula 9:

$$\tilde{J}(i, k\Delta t)\ \forall\ t \in [0, \tau]. \quad (9)$$

where $J_i \le 0$ correspond to all controllers; the controller which has minimum $J_i$ is used as the optimal controller in circuit.

The flowchart of the unfalsified control algorithm is shown in Fig. 3.

## 3. Simulation Results

The simulation parameter is designed as follows. The candidate controller consists of 30 groups of controllers with $P$, $I$, $D$ and $K_P = \{5, 10, 25, 80, 110\}$, $K_I = \{2, 50, 100\}$, $K_D = \{0.5, 0.6\}$.

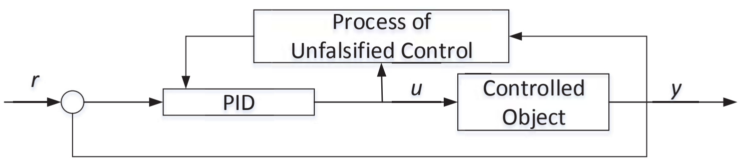


**Fig. 2.** Configuration of PID unfalsified control system

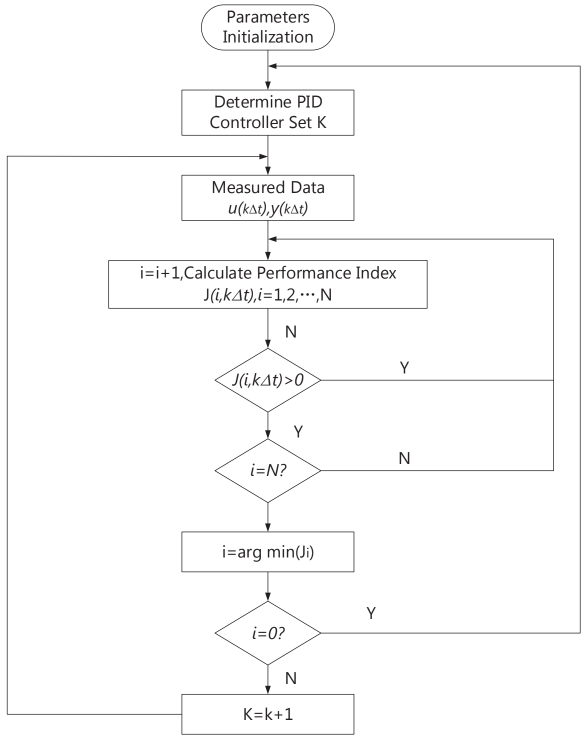


**Fig. 3.** Flowchart of the unfalsified control algorithm

The transfer function of the unknown object is expressed as $P(s)=\frac{s^2+2s+10}{(s-1)(s^2+2s+100)}$, other simulation parameters include $W_1(s)=\frac{s+20}{2(s+3)}$, $W_2(s)=\frac{0.01}{1.2(s+1)^3}$, sampling time of $\Delta t = 0.05s$, $\varepsilon = 0.01$. The initial condition is $\rho=0$, the step signal is used as input signal. The simulation results are shown in Fig. 4–7.

The 30th controller is chosen as the initial controller, the corresponding parameter is [5, 2, 0.5]. As shown in the simulation results, this parameter group cannot meet the command the performance index of the system, since the system is not stable thereat. Hence, The controller is switched. The parameter group [110, 100, 0.6] is chosen as the optimal one. As shown in Fig. 4, a good output response is achieved and the system is stable. In summary, with unfalsified control, whether the controller can meet the performance index is judged by the real-time measured data. If so, the best controller is chosen, while other controllers are abandoned. Parameter-adaptive tuning of PID control is realized by means of unfalsified control.

Interference is inevitable in actual systems. To address this issue, simulation results with noise and impulse interference are shown in Fig. 8–15.

Band-limited white noise with amplitude of 0.1 and sampling time of 0.1 s is added to the system; the simulation results are shown in Fig. 8–11.

Pulse perturbations with amplitude of 1 and cycle of 2 s are added to simulation; the results are shown in Fig. 12–15.

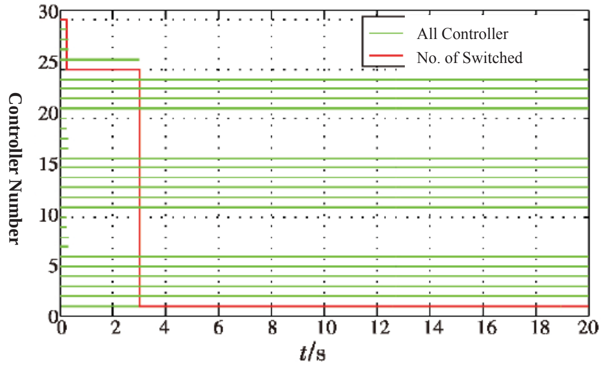


**Fig. 4.** Switching sequence of controllers

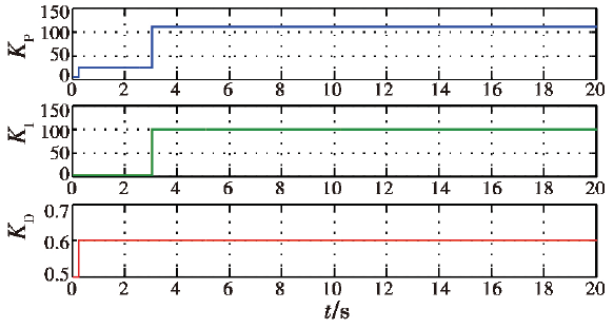


**Fig. 5.** Switching of PID parameters

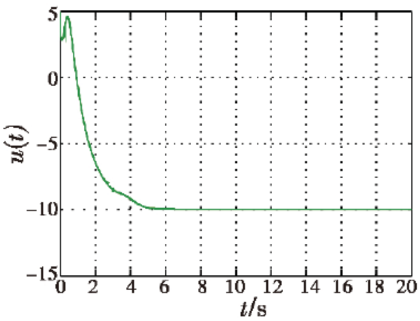


**Fig. 6.** System control input

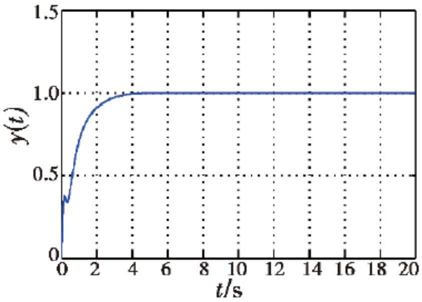


**Fig. 7.** System output

As indicated by the charts, when pulse perturbations and noise interference are added to the system, stable output can still be achieved with the help of unfalsified control, which can choose the best PID controller. A high anti-interference ability can be achieved when unfalsified control is used in the PID parameter tuning.

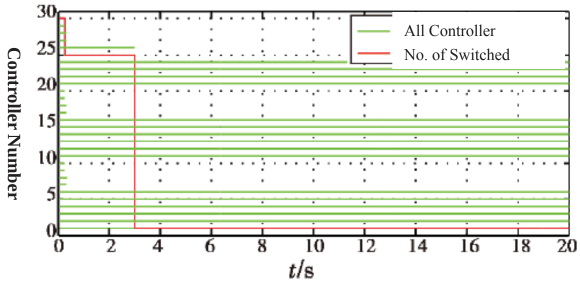


**Fig. 8.** Switching sequence of controllers (noise)

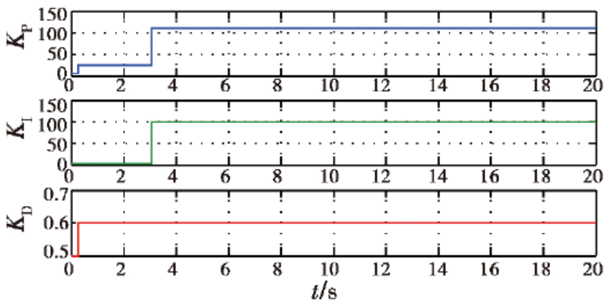


**Fig. 9.** Switching of PID parameters (noise)

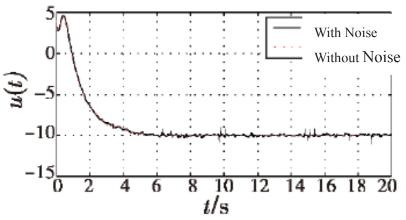


**Fig. 10.** The contrast of control input (noise)

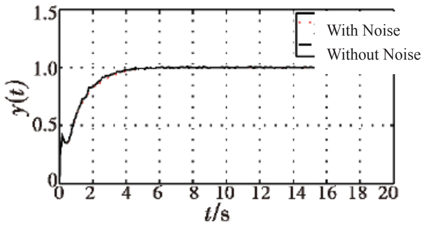


**Fig. 11.** The contrast of output (noise)

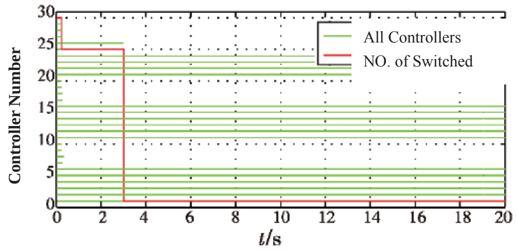


**Fig. 12.** Switching sequence of controllers (pulse)

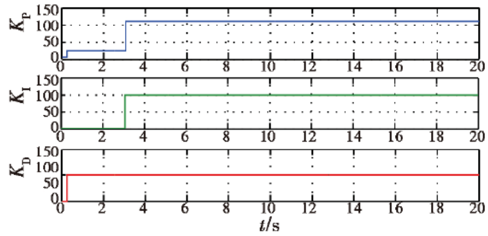


**Fig. 13.** Switching of PID parameters (pulse)

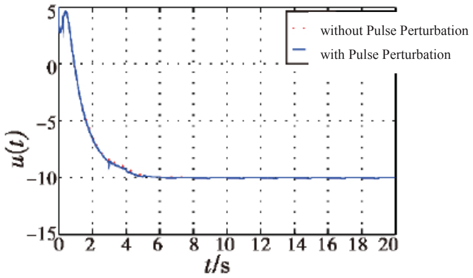


**Fig. 14.** The contrast of control input (pulse)

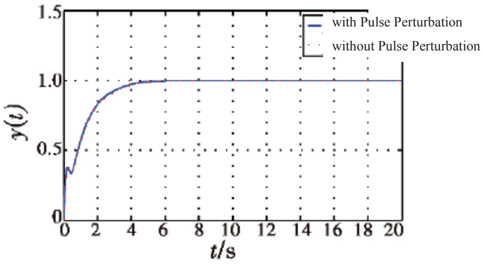


**Fig. 15.** The contrast of control input (pulse)

**CONCLUSIONS.** In this paper, we have studied the unfalsified control theory and applied it to the PID parameter self-adaption. The study shows the stabilized, fast and effective controller switched into cycle is based on the unfalsified control theory. With the continuous improvement, the unfalsified control theory will be widely implemented in practice.



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