Research on MPC Algorithm of Human Simulating Predictive Control in Energy Storage and Modeling of Stepping Motor

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Abstract: The essence of energy storage and release in the power system is the process of converting the driving mode of the motor, stepper motors have the advantages of fast speed regulation, high output power, and high stability, but its dynamic modeling structure is relatively complex, requiring comprehensive consideration of factors such as mechanical transmission and balance of each component, circuit safety, etc. The article proposes an MPC (Model Predictive Control) algorithm based on humanoid thinking, addressing errors and fluctuations in energy storage during the establishment of model structures, simulating the interaction between manual intervention and automatic control can handle issues such as parameter collection mismatch and mathematical model mismatch. Solving the problem of mutual constraint of parameters in the energy storage structure of stepper motors, which affects the stability and error fluctuation of motor energy storage. When the model structure does not match, the humanoid MPC algorithm does not require accurate model parameters, the energy storage process can be controlled through manual adjustment based on the output results and feedback requirements. It has the advantages of clear physical concepts, high accuracy in simulating human thinking modeling, fast error adjustment and output response time, and high stability.

Keywords: Energy Storage in the Power System; Modeling of Stepper Motor; MPC Algorithm; Predictive Control; Humanoid Thinking

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1 Introduction

The operation of power systems and stepper motors must meet safety and stability requirements, the output capacity of the stepper motor meets the total electricity demand for long-distance and high-power loads, even if there is a rapid decrease in voltage loss in the transmission line, the total electrical capacity can still be maintained within a reasonable set value range. Wang et al. [1] analyzed shows that the establishment of mathematical models corresponding to output feedback and input also has dynamic characteristics, that is, the occurrence of energy storage and modeling overshoot and under-voltage causes unstable electricity consumption of stepper motors and line transmission. In the power system structure, there are human factors that can affect the energy storage and compensation results of stepper motors in energy storage and reactive power compensation cal-

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culations, if parameter distortion causes vibration energy storage and mismatch between energy storage and modeling, resulting in unsatisfactory energy storage and modeling effects.

For automatic energy storage and modeling design solutions, it is possible to autonomously switch and calculate electrical energy losses based on the monitoring status of load operation, the selection of compensation capacitor banks is based on the closed-loop feedback parameters of the circuit, online operation trajectory, and online optimization calculation conditions to determine whether the energy storage and modeling exceed the set values for compensation. Tu et al. [2] analyzed the characteristics and circuit functions of automatic energy compensation in power systems are elaborated, and a mechanical component trigger switch based on the sampling sensor structure is designed. The mechanical part is controlled by the switch contacts at the output end of the stepper motor, and the sensor signal is fed back to the stepper motor drive chip, triggering a closed-loop control system for automatic energy storage, modeling energy storage, and compensation. Ling et al. [3] analyzed the circuit part includes compensation value limit switches, sensing sampling and signal feedback, stepper motor trigger pulse control, automatic energy storage and modeling angle and displacement to determine whether the energy storage and modeling have adjustability.

Ding et al. [4] analyzed based on the characteristics of automatic energy storage and modeling range, which can not only meet the total electricity consumption of the load but also monitor the total loss of the line and main equipment in real-time, etc. According to the control algorithm of the predictive model, online decision calculation and optimization are carried out to achieve the design concept of intelligent automatic energy storage and modeling enhancement or reduction. The practicality and safety have been verified through multiple experiments.

In summary, the biggest problem with using stepper motors for energy storage and modeling is their fast response and high accuracy. The method of using energy storage stepper motors to drive and cycle control contacts for switching is a good way to distinguish and classify the correlation between the total electricity consumption and loss of electricity in power loads. Ensure synchronous enhancement or reduction of energy storage and modeling, with high safety and stability.

2 The Principle of Energy Storage and Compensation for Stepper Motors

The main characteristic of energy storage in stepper motors is the stability of load energy operation after compensation, and the closed-loop sampling of physical parameters in the sampling circuit, if the feedback system of the stepper motor drive control is triggered, the input sensor collects parameters such as the closed-loop current and voltage, displacement, angle, etc. of the circuit, forming an interactive and stable closed-loop system with the main control of the stepper motor [5]. The characteristics of energy storage and modeling are timely and fast output feedback commands, which can respond to the driving process of stepper motors, and complete the control of automatic energy storage and modeling. Its feature is that the limit switch provides a command to the stepper motor, which opens the automatic compensation circuit (active time-varying process).

According to the closed-loop conditions of the circuit, the information is autonomously fed back to the stepper motor system, driving the stepper motor to store and compensate energy, preventing automatic energy storage and modeling from being too high or reduced. Its control strategy requires a complete switch pulse command to execute and trigger, and sensors collect variables such as closed-loop current and voltage pressure in the circuit, the motor energy storage and modeling can calculate the offset angle based on the compensation conditions by setting the voltage, making it easy for compensation to obtain sufficient reactive power compensation.

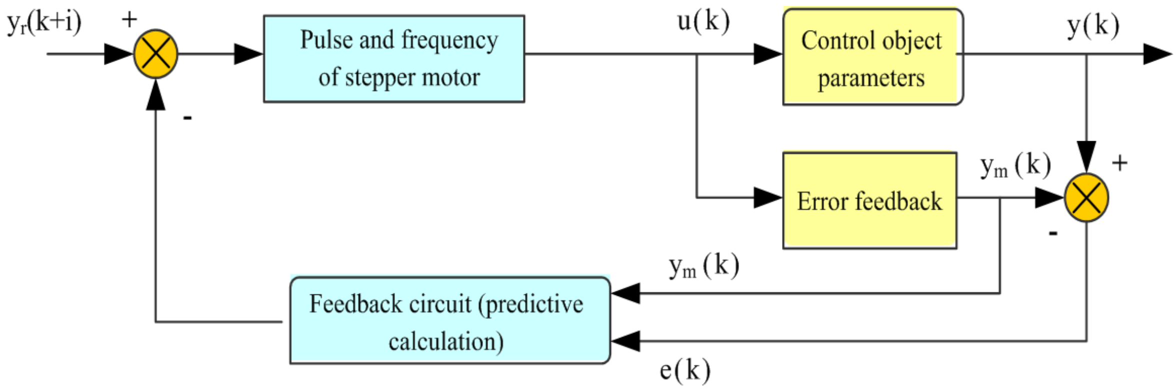

Figure 1 Stepper motor drive circuit structure and feedback mode

As shown in Figure 1, set the sampling time of the stepper motor with input reference values y(k), $y_r(k+i)$, time change reference t(k+i), stepper motor output control value y(k), feedback comparison and calculation result u(k), error optimization control output $y_m(k)$. The error rate time varies with the sampling parameters for each comparison result e(k) - e(k-1). Namely:

$$|X_2-X_1|\leq e(k);\ldots\ldots;|X_n-X_{n-1}|\leq e\ (k-1)$$

Based on the characteristics of predictive control structure, set the historical information of the controlled object {u(k-j), y(k-j) | j ≥ 1} and the feedback model input {u(k+j-1) | j=1,..., m}, and calculate the output result of the predicted object {y(k+j) | j=1,..., p}.

Equipped with n sets of sensors for a certain control object, calculate the feedback model based on external factors such as current and voltage over time, and collect 10-20 sets of data per hour to measure and analyze the parameters collected in real-time by the energy storage and modeling circuits [6-7]. According to the validation of the X_i (i=1, 2..., n) parameter, the set error e should not exceed the difference between adjacent values of X_1, X_2,..., X_n according to the validation criteria.

The compensation strategy is to optimize the input and output of the circuit control and feedback system while meeting the requirements of safe energy storage and modeling of the load, simulate the characteristics of human thinking compensation and energy switching, and use the MPC algorithm of predictive control in the stepper motor drive circuit and energy storage and modeling circuit, energy storage and modeling circuit characteristics for online optimization and calculation of dynamic model structures.

3 Principle of Humanoid Predictive Control Based on MPC Algorithm

Predictive control is a control strategy platform with a low online demand model, convenient calculation, good real-time performance, and good control effect. MPC (Model Predictive Control Algorithm) is a common algorithm system widely used in predictive control algorithms, which has good smooth models and support vector features. Its characteristic is that the mathematical model is accurate and the modeling process meets the requirements of the control strategy, if the model cannot be established or the parameters are mismatched, predictive control requires human intervention in its control process, resulting in exacerbation of the stepper motor system, the stepper motor may experience vibration when storing electrical energy and compensating, resulting in large errors in parameter output and feedback calculation. The overall control is completely detached from the regulation and control platform, and online calculation and control requirements make it difficult to achieve the expected goals.

MPC algorithm can be used to solve several engineering applications:

(1) MPC algorithm has good adjustment for the delayed performance of the system;

(2) The controlled object has constraint conditions and feedback characteristics;

(3) The system should have a large number of input/output control variables with multiple sampling and variations;

(4) The imbalance between the change of control purpose and the setting parameters of the controlled equipment.

A. The Structure and Online Calculation of Predictive

Control

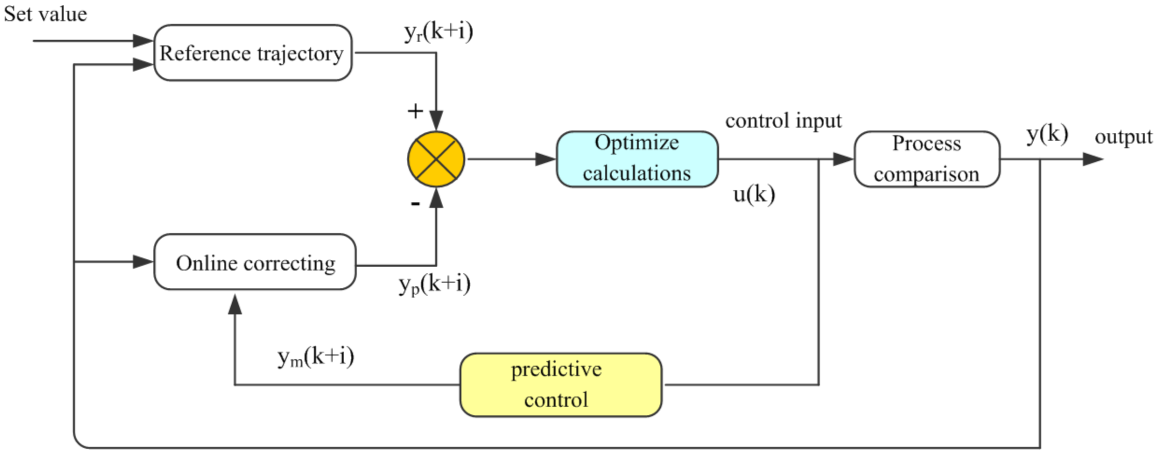

Figure 2 Schematic diagram of predictive feedback control structure

Figure 2 shows, the composition of the predictive control structure, which includes: the predictive model, rolling optimization correction, feedback correction, and adjustment. In its structure, human intervention is used to add output errors to the prediction model for feedback online correction [8]. Each optimization step is based on the latest basic data obtained from the actual process, therefore:

$$y_r(k)=y(k) \tag{1}$$

Reference trajectory equation:

$$y_r(k+i)\text{-}a_i y(k)+(1\text{-}a_i)w \tag{2}$$

In equation 2, $y_r(k+i)$ is the reference trajectory at time k+i; Y(k) is the actual output value of the process at time k. The attenuation system a=e-T/T, (0<a<1) T_r is the time constant of the reference trajectory $y_r(t)$; w is the output set value; i=1, 2,…

Then optimize the objective function:

$$J_{\min}=\sum_{i=1}^{P}[y_p(k+i)-y_r(k+i)]^2 q_i \tag{3}$$

From equation 3, it can be seen that qi ($0<q_i\leq 1$) is a weighted coefficient. The calculation and optimization process of its prediction model consists of four components: the original structural model, reference compensation trajectory, online optimization stage, and prediction feedback and calculation stage, or online correction and optimization.

B. The Characteristics of MPC Algorithm in Predictive Control

The MPC (Model Predictive Control) algorithm is a rolling calculation control method based on online optimization, which describes the controlled object and output control under constrained optimization conditions, and combines the advantages of DMC (Load Matrix Control), MAC (Model Algorithm Control), and GPC (Generalized Predictive Control) algorithms. Feedback is the process of extracting a portion of information from the output of the controlled object as the next input, and then having an impact on the output [9]. Determine the optimization problem and repeat the calculation and correction of the control process online, gradually requiring the best control effect to be achieved.

Therefore, using mathematical models and feedback information is a better strategy for correcting predictive control, at the same time; uncertainty plays an important role in overcoming interference in energy compensation and safe storage of stepper motors. MPC predictive control and output error feedback correction can be used to accumulate errors in predictive control model calculations, with strong response speed and stability robustness.

The stability of the MPC algorithm and predictive control model tends to decrease when there is parameter mismatch and model structure changes, it has advantages in logical reasoning, feedback calculation and judgment, and output structure optimization, while the interference deviation of electric energy storage and error compensation of stepper motors are close to the idea of human intervention, once the set value is exceeded, the control circuit will be automatically cut off, and within the compensation range, the control strategy will naturally operate. The mathematical modeling of the control strategy is simple, the concept is clear, and it has the thinking inertia of simulating human operation.

4 Strategy Process for Implementing Energy Storage and Modeling for Stepper Motors

MPC predictive controller is a simulation of human active open-loop control and strong time-varying control. The characteristic of humanoid thinking control is to simulate human thinking experience, and its common feature is active time-varying control. The combination of the two is a comprehensive simulation of human control thinking characteristics, which does not completely intervene in the process of controller action, but timely deals with problems such as increased local parameter errors caused by stepper motor energy storage and modeling.

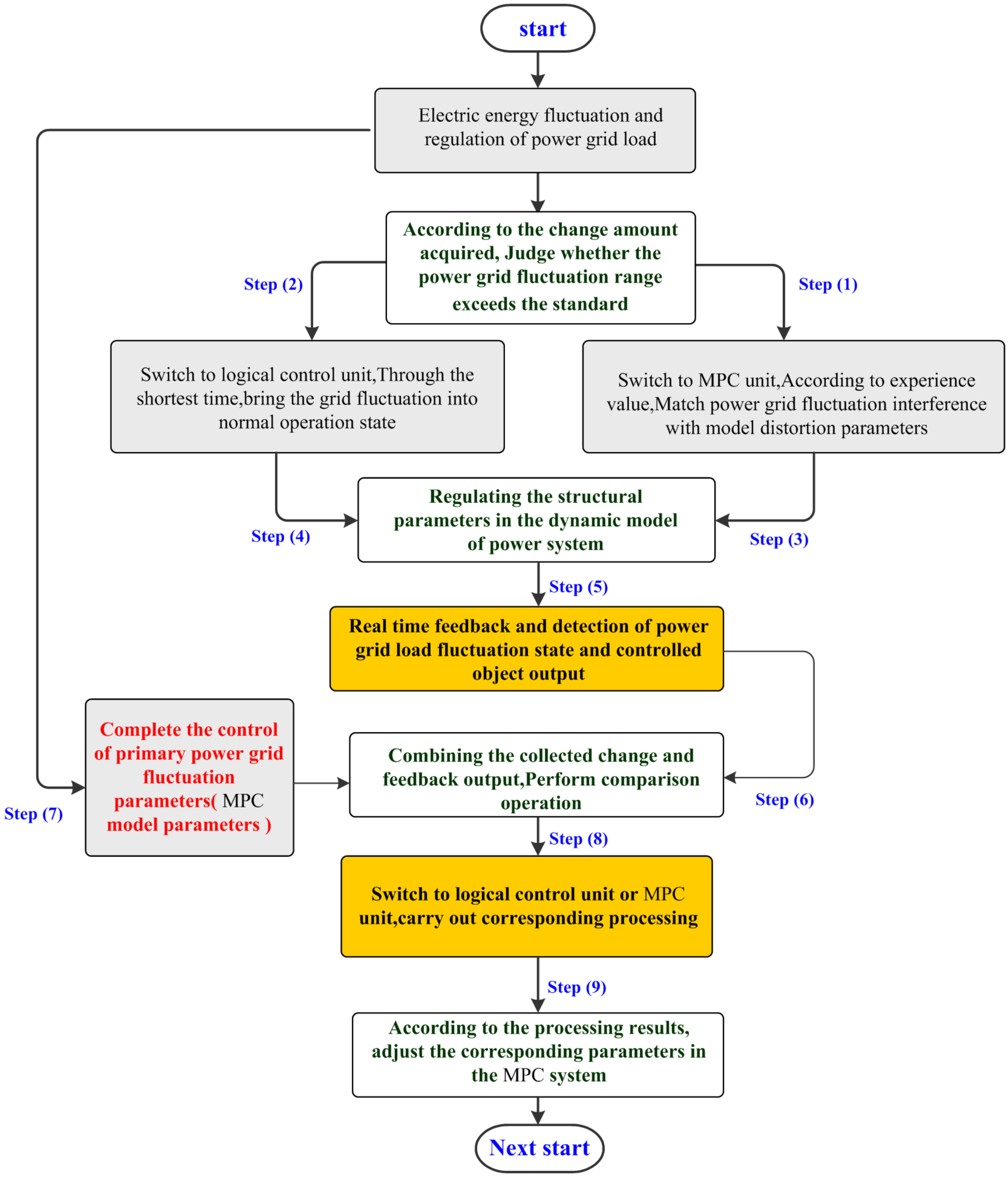

Figure 3 Process flowchart of energy storage and compensation strategy for stepper motors

As shown in Figure 3, the energy storage and modeling of the stepper motor adopt a model estimation with multiple parameters, and the interaction strategy of manual intervention and predictive MPC control is adopted if dealing with external influences such as model parameter distortion and interference noise, the detection process of load electricity consumption must require fast response and high accuracy. Propose this design concept and observe the operation of the circuit. It is found that: experienced operators will proactively and without hesitation cut off the stepper motor or feedback control when the system exceeds the limit value or even experiences frequent changes in error rate, when the system is operating within a normal range, it is controlled based on experience to minimize fluctuations in energy storage and modeling.

In summary, the humanoid thinking of its control strategy is more in line with the combination of circuit closed-loop control and strong time-varying control [10], through certain experiences and appropriate structural adjustment, manually setting parameters to adjust the fuzzy controlled object, the control effect is relatively ideal. Have three characteristics:

(1) The energy storage and modeling of the stepper motor system adopt a control strategy to restore stability, maintain its stable operation, and achieve the best matching of adjustment speed and measurement accuracy.

(2) Effectively suppress and overcome hysteresis delay and oscillation harmonics in stepper motor systems.

(3) By switching between predictive control and manual intervention, the energy storage and modeling parameters of the stepper motor can be quickly and accurately controlled, which can enable energy storage and modeling errors to quickly, stably, and accurately reach or approach set values.

The result of its manual intervention operation: When the motor operates in a stable range with the load energy, it ensures the safety of the compensation circuit and the accuracy of parameters. If there is a sudden structural change or uncertainty that can still ensure satisfactory operation, the protection motor energy storage and modeling circuit can be switched instantly [11]. The relationship between output results and input quantity is not dependent on. Although this handling control method is not globally optimal, failure to intervene promptly can affect the overall control effect when there is severe interference and distortion in local circuits, especially in certain electrical equipment, ensuring local optimization based on strong robustness.

5 Experimental Results and Modeling Simulation Analysis

Select the control parameters for the stepper motor: adopt a four-phase four-beat operation mode with a reduction ratio of 1:64 and a step angle of 5.625/64. Turning one circle requires 360/5.625 * 64=4096 pulses. The driving signal is a pulse signal, and the stepper motor is stationary when there is no pulse. By adding an appropriate pulse signal, it will rotate at a certain angle (according to the principle of symmetrical energy storage, the input condition is stable at 120 degrees, and the motor rotation speed and frequency are calculated as one-third of the PWM modulation pulse width of one cycle).

Using impulse as the input parameter for the simulation model, establish a mathematical model for the energy storage and energy storage of stepper motors in the modeling system, its control process has second-order system characteristics [12], such as overshoot, fast response time, rise period, delayed output and feedback regulation, damping oscillation and harmonic disturbance, etc. Set the sampled input model predictive control (MPC) as:

$$G_1(s)=\frac{3(1-e^{-\tau s})}{2s^2+3s+4} \text{ (Model matching with delay),}$$

$$G_2(s)=\frac{8e^{-\tau s}}{2s^2+3s+4} \text{ (Model Mismatch)}$$

During the process of load energy storage and modeling, analyze the errors and delay phenomena that occur, and simulate when the system predictive controller is working simultaneously. The energy storage and modeling of the interference stepper motor are gradually optimized online, and its MPC predictive control strategy and Simulink modeling process conform to the characteristics of variable parameters and structural mismatch. The method is similar to manually controlling the error range of overshoot.

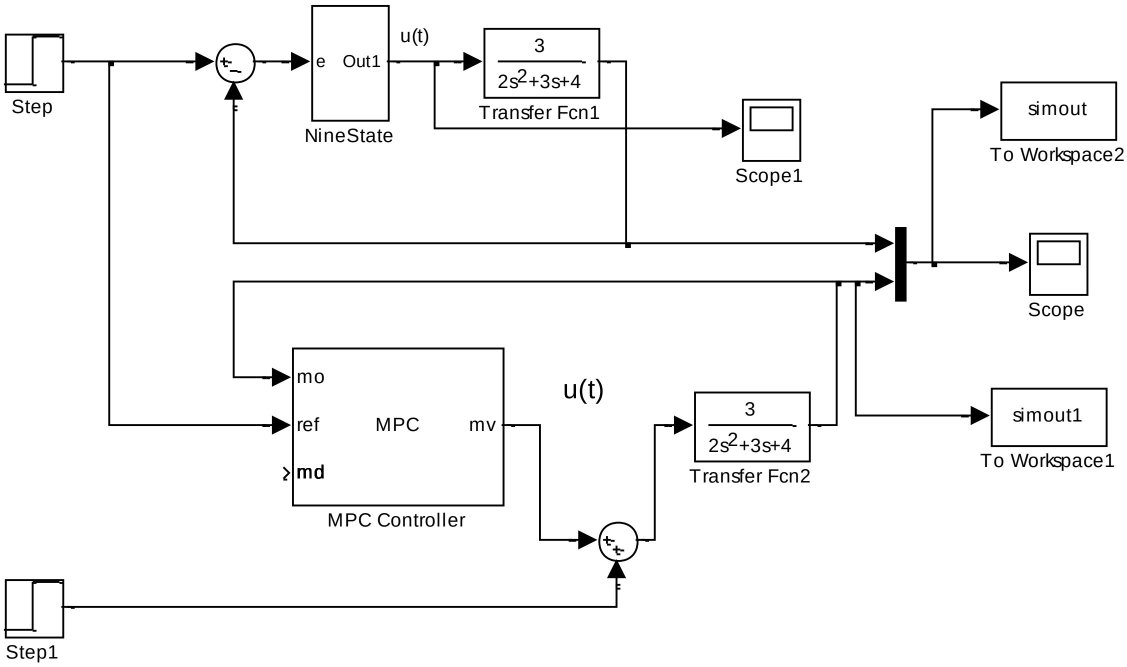

Figure 4 Simulation structure diagram of MPC prediction model and controller strategy (model matching and delay control)

Table 1 Measurement and error detection data of collected parameter specimens

Sampling	Sample size for simulation experiments (model matching and parameter mismatch)		
	Sampling data (Input)	Measurement data (feedback and output)	Distortion error
1-2	14.6300+24.5340i	14.6301+24.5339i	-0.0001+0.0001i
3-4	16.9281+22.7004i	16.9370+22.7013i	-0.0089-0.0009i
5-6	18.1450+20.2543i	18.0079+20.8432i	0.1371-0.5889i
7-8	27.3562+24.8645i	26.9873+25.3612i	0.3689-0.4967i
9-10	22.2351+18.5231i	22.1032+19.5217i	-0.8681-1.9986i

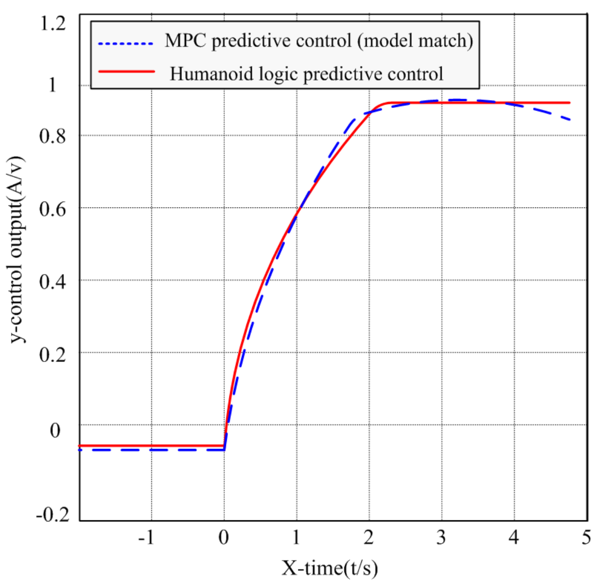

Figure 5 Predictive Output Control of MPC Algorithm (Model Matching Delay)

As shown in simulation figure 5, it can be concluded that utilizing the fuzzy attributes of low model requirements and predictive MPC control, if the model is difficult to establish or the parameter distortion model is unstable, the output results and compensation effect will not reach the ideal state. Combining system identification function with humanoid thinking for manual intervention, the operator's experience will have a good control effect.

(1) Consistency of control parameters for stepper motors ensures synchronous increase and decrease of energy storage devices, with high safety and stability. Timeliness of sampling power supply load environmental parameters, triggering motor drive control energy recovery device;

(2) The sensor collects the error rate of temperature and humidity, displacement, angle, and other parameters of the electrical load, and forms an interactive and stable closed-loop system with the main control of the stepper motor.

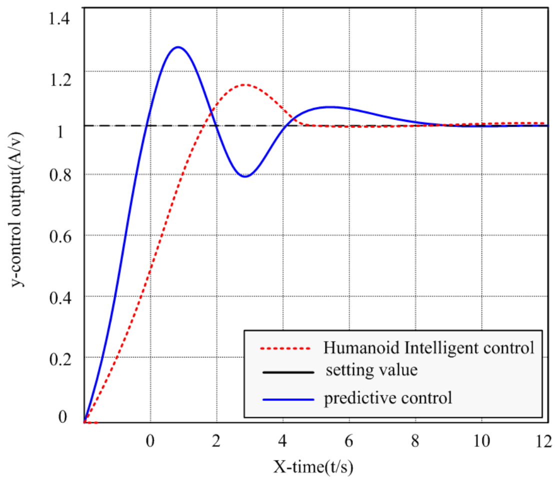

Figure 6 Humanoid Predictive Intelligent Controller (Model Mismatch, No Delay)

As shown in Figure 6, the control characteristics of humanoid thinking are as follows: energy storage and modeling do not require direct predictive control and feedback within constrained ranges and conditions, At this point; the role of active control is reflected. Humanoid thinking is to observe the load of the stepper motor running until the electrical energy drops to a certain extent, manually intervene in the compensation process, switch the operating mode of the compensation circuit, and integrate the MPC algorithm into the predictive control model to achieve the expected interaction between motor energy storage and modeling.

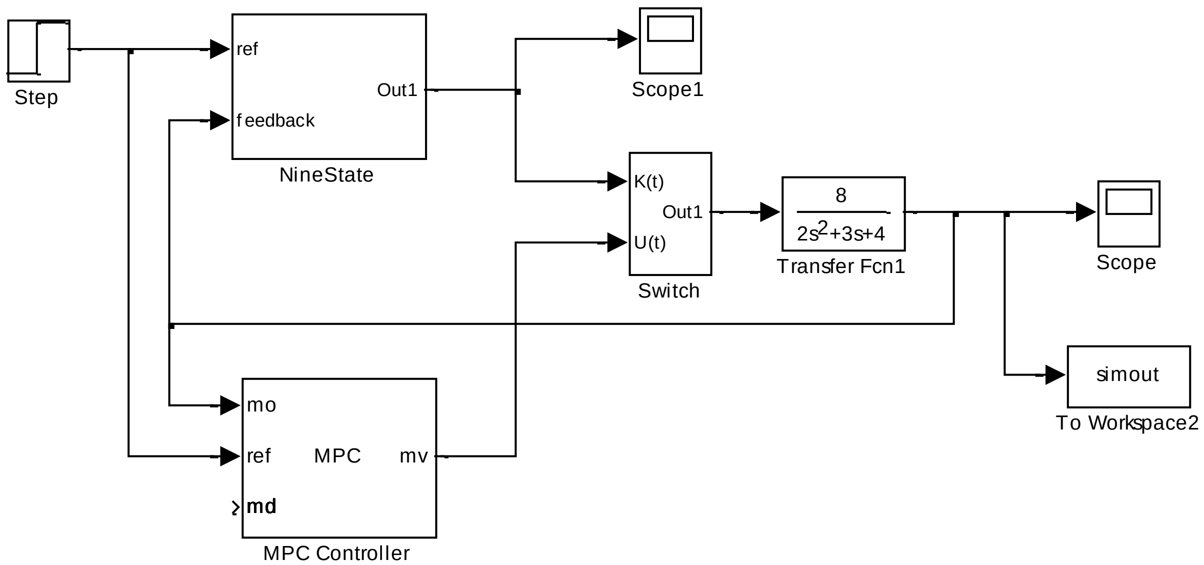

Figure 7 MPC prediction model and HLPC humanoid logic controller strategy structure (model mismatch and overshoot control).

Table 2 Measurement and error detection data of collected parameter specimens

Sampling	Sample size for simulation experiments (model matching and parameter mismatch)		
	Sampling data (Input)	Measurement data (feedback and output)	Distortion error
11-12	19.9784+23.6452i	19.4976+24.1722i	0.4808-0.5270i
13-14	28.5679+21.1567i	28.0325+20.1366i	0.5354+1.0201i
15-16	26.2485+20.1354i	26.2481+20.0326i	0.0004+0.1028i
17-18	28.2101+19.7925i	28.1081+19.7058i	0.1020+0.9133i
19-20	26.6232+20.1021i	26.7400+20.4384i	-0.1168+0.6637i

As shown in Figure 7, the MPC prediction algorithm has an online optimization control strategy based on large-scale inputs, input constraints, and feedback rolling towards stable values, a matching model is established for fast response and compensation of stepper motors, which solves the problems of robustness and stability during operation [13]. The control behavior in MPC prediction structures has at least three characteristics:

(1) Active open-loop or semi-closed-loop feedback systems;

(2) Strong time-varying intervention system;

(3) A certain understanding and operational experience in the characteristics of electric energy storage and circuit compensation structures.

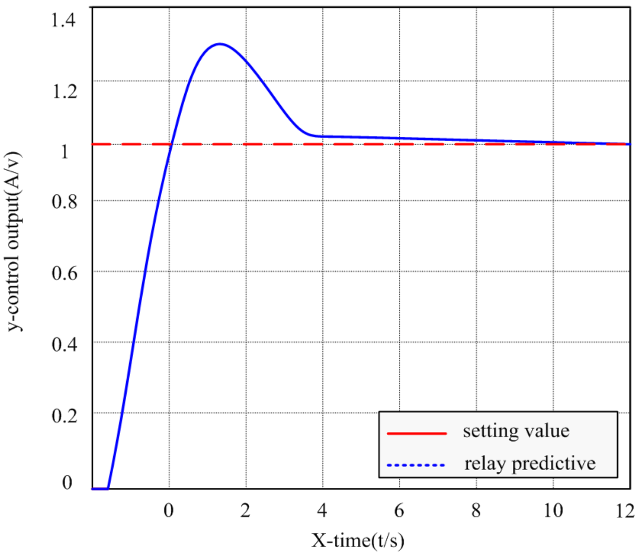

Figure 8 Humanoid Predictive Control Output (Model Mismatch, Delay)

As shown in Figure 8, it is demonstrated that the time optimal control of input compensation is directly controlled by the predictive model, and the final overshoot curve is close to the set standard value, achieving stable operation.

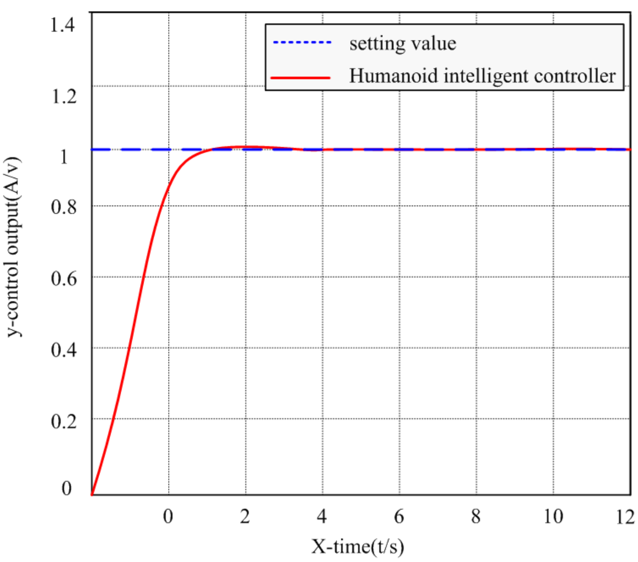

Figure 9 MPC Predictive Control Algorithm Strategy (Model Matching)

Set a period t, where the temperature remains within an effective range of fluctuations or changes that meet energy storage conditions and will not trigger the recovery system. The error rate is set to e(t) - e(t-1); Based on the changes in the output results of the predictive feedback model, optimize the feedback error control range after sensor acquisition and processing. The data collection error of the original sensor will also be controlled, and the error rate, fluctuation, vibration interference, and other external influences will not cause accidents such as instability of the energy storage device recovery system and motor system, ensure that this type of control simulates the thinking control characteristics of humans, is easy to control for fluctuations or disturbances, improves accuracy, and has the characteristic of low delay feedback.

As shown in Figure 9, simulating the thinking characteristics of humans in control can observe the thinking behavior controlled by experienced operators, the energy storage and modeling of stepper motors result in errors and overshoot of power loads, indicating changes in the system model structure and parameters, which affect the safety and stability of stepper motor operation.

To ensure the stability and low deviation rate of the sampling signal, the feedback stepper motor triggers automatic energy storage and modeling of the sampling values, avoiding sensitivity reduction caused by changes in circuit closed-loop parameter values for energy storage and compensation. The changes in the closed-loop parameters of the input circuit affect the accuracy of the sampling values, overcoming the stability issues of delay and rapid response decline in energy storage and modeling of stepper motors, enhancing the overall performance of the system in the event of model mismatch and improved its robustness.

6 Conclusions

Simulating the characteristics of human thinking control, MPC algorithm has a certain understanding of the system characteristics and structural models of energy storage, experienced operators will perform necessary manual interventions to avoid significant fluctuations in sampling parameters that could affect the stability of energy storage.

The experimental simulation in the article is based on the energy storage method of stepper motors and the semi-automatic control method of simulating human thinking for parameter sampling, the control strategy of MPC algorithm plays an important regulatory role in the environment of parameter model mismatch. The simulation results show that it performs better than predictive control in dealing with interference fluctuations and energy storage stability.

The combination of MPC algorithm and motor energy storage structure modeling does not require precise mathematical derivation and modeling formulas, need to understand the output and feedback status, and adjust the input parameters based on the control results. Its characteristics are similar to simulating humanoid thinking, as long as the output results match the prediction, it adopts an automatic control+motor-driven energy storage method. When there is a parameter mismatch or structural change, based on the feedback constraint conditions, a semi-automatic intervention control with artificial simulation is adopted, the MPC algorithm will automatically adjust variables according to control requirements to ensure that the control results and feedback conditions meet expectations.

Experimental results have shown that this control strategy can ensure good stability and response time of motor energy storage without model distortion, once an error or fluctuation occurs, the system will automatically intervene to quickly control overshoot and delay, it has important guiding significance in actual industrial production.

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