Research on structure optimisation method of 3D printer based on decoupling parallel connection

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Abstract: In order to improve that mechanical distribution and automatic control capability of the 3D printer structure, a decoupling control method of the 3D printer structure is proposed based on the decoupling control, and a mechanical distribution model of the 3D printer structure is constructed. The linear decoupling method is used to adjust the position of components, high resolution printing structure parameters feedback tracking fusion method is used for parameter allocation and error correction. By constructing the reliability control price constraint condition, the global optimal solution is obtained to realise the optimisation of the decoupling control of the 3D printer structure. The simulation results show that the stability of the 3D printer structure decoupling control is high, the self-adaptive performance is good, the mechanical automatic distribution capability of the 3D printer structure is improved, and the output resolution capability of the 3D printer is improved.

Keywords: decoupling parallel; 3D printer; structure; control; high resolution.

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1 Introduction

With the development of artificial intelligence technology, various mechanical arms and mechanical hands appear and gradually replace the complicated manual labour, the intelligent level of the mechanical assembly is improved, and the 3D printer structure is used as a common mechanical arm component, The mechanical automatic distribution and decoupling control of the 3D printer structure is the key to the design of the manipulator, and the decoupling control method of the 3D printer structure is studied, and the mechanical automatic distribution capability of the mechanical structure component of the printer is improved, the three-dimensional printer is also called a 3D printer, is a cumulative manufacturing technology for three-dimensional printing by using a ‘ink-jet’, and a special wax material is applied to the 3D printer structure, The mixing of data and raw materials, such as powdered metal or plastic, which is carried out using a machine program, the printed product is computer-modelled, the ‘ink’ used by the 3D printer structure is a solid raw material, a layer of extremely thin powder particles are sprayed on the mould in a ‘ink-jet’ manner, the powder particles are melted by the melt-product formed electron flow in the vacuum, the data and the raw materials are put into the mould tray, and the product is printed on a layer-by-layer basis. and then the data is transmitted and output through the SD card or the USB flash disk (Zhang et al., 2016), the three-dimensional output is realised by the pre-design of a complete three-dimensional 3D model, the 3D printer structure is in the automobile, the aerospace, the machine manufacturing, the printing speed of the 3D printer is an important parameter reflecting the working efficiency of the printer, and the 3D printer structure can improve the production and production efficiency of the 3D printing and the three-dimensional model, The control performance optimisation algorithm for 3D printer structure is of great significance (Schöbauer et al., 2015).

The decoupling control of 3D printer structure is based on the extraction of mechanical characteristic parameters and the optimisation design of control law for mechanical structure components of flexible printer. In the traditional methods, the main decoupling control methods of 3D printer structure are fuzzy PID control method, sliding mode control method and so on (Liu et al., 2016). The constraint parameter model of 3D printer structure decoupling control is constructed. Combined with the analysis of mechanical parameters of 3D printer structure, the control law is designed, and good control effect is obtained, but the above methods have the problems of poor adaptability and low robustness in the mechanical decoupling control of 3D printer structure. At present, the structure of 3D printer adopts single fixed data transmission, which affects the printing speed. In 3D printing, the technology of ‘laser sintering’ is used to solidify the 3D model with liquid adhesive. The thickness of the cross section of the printer is usually 50 to 100 microns. Due to the use of single fixed data transmission and layer by layer printing, the printing speed is seriously affected. In this regard, the related literature has carried on the research on improving the printing speed of 3D printer structure. In Mackay et al. (2017), a desktop 3D printing technology based on LU decomposition and parallel processing is proposed. The mechanical components and printing heads of 3D printers are combined by singular decomposition to improve the printing speed of the printer. However, the model needs layer by layer printing to construct the model space. It cannot effectively realise the equilibrium processing in the balance of wax and powder metals, and needs to be improved. In Wu et al. (2017), a printing speed evolution method based on 3D printing quality level and production efficiency benefit index optimisation is proposed. The multi-objective closeness control mathematical model of 3D printing is constructed. The optimal proportional configuration of data and raw materials is realised by cybernetics method, which improves the printing speed, but the algorithm needs to determine the printing parameters according to the size and complexity of the printing model. The accuracy of printing cannot be guaranteed in the case of lack of prior knowledge.

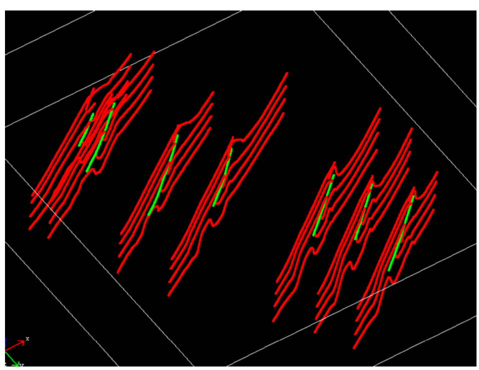
In order to solve the above problems, a decoupling control method of 3D printer structure based on decoupling parallel is proposed in this paper, the mechanical distribution model of 3D printer structure is constructed, the stable position of printer mechanical structure components of 3D printer structure is adjusted by linear decoupling method, and the mechanical parameters distribution and error correction of 3D printer structure damping unit and spring unit are carried out by using high resolution printing structure parameter feedback tracking fusion method. The decoupling control law of 3D printer structure is designed under decoupling parallel. The stability region of 3D printer output torque change is taken as the reliability control price constraint condition of 3D printer structure, the global optimal solution is obtained, and the decoupling control optimisation of 3D printer structure is realised. finally, the simulation experiment is carried out, which shows the superior performance of this method in improving the decoupling control ability of 3D printer structure.

2 The description of the controlled object and the analysis of the constraint parameters

2.1 3D printer structure controlled object

In order to realise that decoupling control of the 3D printer structure, a constraint parameter model of the stability control of the 3D printer structure is first constructed, and the mechanical parameter dynamic analysis of the 3D printer structure is carried out in combination with the optimisation identification of the parameter model (Guo and Guo, 2016; Kim and Lee, 2018). The frame point distribution structure rigid body model for 3D printing is shown in Figure 1.

Figure 1 Frame point distribution model of a 3D printer structure (see online version for colours)



In consideration of the decoupling parallel constraint, the identification model of the control parameters of the 3D printer structure is as follows:

$$\begin{cases} \dfrac{dx_1(t)}{dt} = f_{x_1}\left(x_1^0, x_2^0\right)\left(x_1 - x_1^0\right) + f_{x_2}\left(x_1^0, x_2^0\right)\left(x_2 - x_2^0\right) \\ \dfrac{dx_2(t)}{dt} = g_{x_1}\left(x_1^0, x_2^0\right)\left(x_1 - x_1^0\right) + g_{x_2}\left(x_1^0, x_2^0\right)\left(x_2 - x_2^0\right) \end{cases} \tag{1}$$

$f_{x_1}, f_{x_2}, g_{x_1}, g_{x_2}$ is the lateral and longitudinal control parameters corresponding to the identification ratio point is the position after structural change relative to x_1, x_2. The identification error of a multi-degree-of-freedom parallel flexible machine is analysed, a

3D printer structure constraint parameter model under the five-axis linkage is constructed, and the fuzzy control is performed according to the parameter optimisation adjustment of the 3D printer structure, and in the two-dimensional Bernoulli space, the decoupling control adjustment function of the 3D printer structure

Combined with the mechanical structure component model of single degree of freedom flexible printer, the stiffness and position decoupling model is constructed, and the inertia constraint parameters of 3D printer structure are adjusted. The process reliability adjustment coefficient matrix of 3D printer structure is recorded as follows:

$$A = \begin{bmatrix} a_1 & b_1 \\ a_2 & b_2 \end{bmatrix} \tag{2}$$

The steady state characteristic equation of 3D printer structure is analysed, and the steady state characteristic quantity of mechanical structure is obtained as follows:

$$\begin{cases} \lambda^2 + p\lambda + q = 0 \\ p = -(a_1 + b_2) \\ q = \det A \end{cases} \tag{3}$$

p indicates that the parameter is offline. q is the upper limit of the parameter. When the mechanical structure of the printer acts on a certain force, the stiffness characteristic of the 3D printer structure is recorded as λ_1, λ_2:

$$\lambda_1, \lambda_2 = \frac{1}{2}\left(-p \pm \sqrt{p^2 - 4q}\right) \tag{4}$$

According to the working principle of mechanical structure components of antagonistic flexible printer, the mechanical structure component model of multi-free flexible printer is constructed, which is described as follows:

$$Hac = \lambda_1, \lambda_2 \left[\frac{dx_1(t)}{dt} + \frac{dx_2(t)}{dt}\right] \tag{5}$$

The linear decoupling method is used to adjust the stable position of the mechanical structure components of 3D printer structure, and the modal parameter identification method of 3D printer structure system is combined with the modal parameter identification method of 3D printer structure system for adaptive adjustment and reliability control.

2.2 Mechanical parameter analysis

The error feedback of 3D printer structure is adjusted by means of mechanical parameter adjustment. Under the action of infinite torque ΔT, the static balance relationship is obtained:

$$
\begin{aligned}
&\max\left(H_{ac}\right)\boldsymbol{A}^{(\alpha_1,\cdots,\alpha_m)}\left(\boldsymbol{A}^{-1}\right)^{\left(\alpha_1^{-1},\cdots,\alpha_m^{-1}\right)^T} \\
&=\begin{pmatrix} \alpha_1 a_{1,1} & \cdots & \alpha_m a_{1,m} \\ \vdots & \ddots & \vdots \\ \alpha_1 a_{m,1} & \cdots & \alpha_m a_{m,m} \end{pmatrix}\begin{pmatrix} \alpha_1{}^{-1} t_{1,1} & \cdots & \alpha_1{}^{-1} t_{1,m} \\ \vdots & \ddots & \vdots \\ \alpha_m{}^{-1} t_{m,1} & \cdots & \alpha_m{}^{-1} t_{m,m} \end{pmatrix} \\
&\left(x_1,\cdots,x_m\right)^T \\
&=\boldsymbol{EI}\left(a_i\right)
\end{aligned}
\tag{6}
$$

The transverse residual stress is analysed, the adaptive feedback adjustment of 3D printer structure is carried out under the condition of stable boundary value, and the stress distribution under the action of position transformation relation of printer mechanical structure component is solved. The characteristic matrix $\boldsymbol{x} = (x_1, \ldots, x_m)^T \in \boldsymbol{GF}(2^n)^m$, makes $D_{0+}^{\beta}u(s)$, $G(t, s)f(s, u(s))$ the state parameter distribution of machining decoupling control, and the equilibrium constraint condition under the calculated stiffness condition is as follows:

$$\frac{du}{d\xi} = \sum_{j=0}^{n} j a_j sn^{j-1}\xi cn\xi dn\xi \tag{7}$$

The conjugated gradient method is used to decompose the mechanical characteristics of 3D printer structure. In the accurate position and pose control of the operating arm of 3D printer structure, the linkage control equation is obtained as:

$$g_k + A_k \Delta x_k = 0 \tag{8}$$

Substituting the parameters into the above equation can be obtained:

$$x_{k+1} = x_k - A_k^{-1} g_k \tag{9}$$

Considering the damping error caused by stiffness change, the linkage control optimisation of 3D printer structure is realised by decoupling parallel adjustment method, and the characteristic solution of state parameters is obtained as:

$$x_{k+1} = x_k - \left[H\left(x_k\right)H\left(x_k\right) + \mu_k A\right]^{-1} H\left(x_k\right)H\left(x_k\right) \tag{10}$$

The stiffness error of the two variable stiffness devices is analysed to meet:

$$\dot{s} = 0 \tag{11}$$

It can be seen that the structure decoupling control process of 3D printer designed in this paper converges stably. According to the above mechanical parameter model analysis, the optimal design of the control law is carried out.

3 Optimisation of decoupling control law for 3D printer structure

3.1 Decoupling parallel adjustment of 3D printer structure

On the basis of constructing the mechanical distribution model of 3D printer structure and adjusting the stable position of printer mechanical structure components of 3D printer structure by linear decoupling method, the optimal design of control law is carried out. in this paper, a decoupling control method of 3D printer structure based on decoupling parallel is proposed, adjust the change of stiffness of mechanical structure members of printer, memorise multi-objective optimisation solution, as follows:

$$PF = \left\{ H(X) = \left(H_1(X), H_2(X), ..., H_r(X) \right) \mid X \in \{X^*\} \right\} \tag{12}$$

The optimal parameters of 3D printer structure are solved by decoupling and parallel adjustment under the constraint of heavy torque vector of manipulator. When the fuzzy constraint parameters satisfy the $CH_i(i \in C_1)$, 3D printer structure, the process transfer function is expressed as follows:

$$H(s) = \frac{e^{-L_m s}}{(\lambda_1 s + 1)} H(s) + \frac{(\lambda_2 s) s}{(\lambda_2 s + 1)} H(s) \tag{13}$$

Closed-loop transfer function of mechanical structure components of flexible printer:

$$\frac{PF}{H(s)} = \frac{H_C(s) H_0(s) e^{-\tau s}}{1 + H_C(s) H_m(s) + H_C(s)\left(H_0(s) e^{-\tau s} - H_m(s) e^{-t_m s} \right)} \tag{14}$$

The modified function is obtained by Laplace transformation as follows:

$$F(x) = \sum_{i=1}^{N} s_i^2(x) = s(x) \tag{15}$$

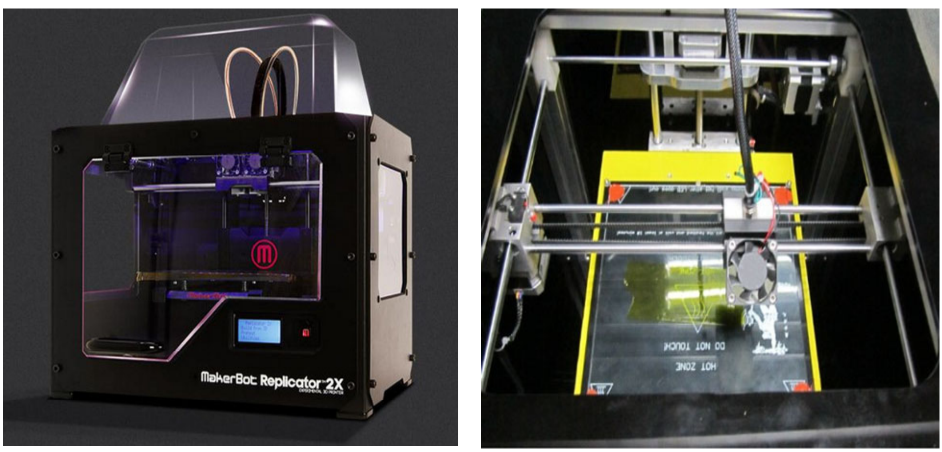
Assuming that $f_i(x_i; \theta_i)$ is the reliability definition distribution function with time delay vector $\theta_i(1, 2, \ldots, n)$ in 3D printer structure, according to the above analysis, decoupling parallel adjustment is carried out to improve the stability of decoupling control (Peng et al., 2017).

3.2 Working principle of 3D Printer structure

In this paper, the improvement method of printing speed of 3D printer structure is studied. Firstly, the working principle of 3D printer structure is analysed. The 3D printer structure studied in this paper is Tim Anderson inkjet printer (Ma and Chen, 2017; Stabile et al., 2017; Wu et al., 2018). The appearance structure of printer and the structure of printer inkjet casting die tray are shown in Figure 2.

The structure of Tim Anderson inkjet 3D printer is modelled by computer modelling software, controlled by control components, mechanical components and printing heads, sprayed with a special layer of glue in the area that needs to be moulded, and bonded to 3D model by using special wax, powder metal or plastics (Feng et al., 2018; Song et al., 2018; Yang et al., 2017). It is necessary to add gel or other substances to realise multi-mode structure, and to transmit printing messages at different frequencies. Then the three-dimensional model is 'divided' into layer-by-layer section, and the 'deposition forming' and layer-by-layer printing, printing objects such as animal model, characters, automobile and building models are realised (Macdonald et al., 2017; Huber et al., 2017). According to the description of the above working principle, the parameter model of printing control of 3D printer structure is analysed. It is assumed that the 3D printer structure system is a decoupling parallel system, the printing system has huge and complex equipment, and each device connects with each other in series.

Figure 2 (a) Appearance structure (b) Inner structure (see online version for colours)



(a) (b)

Source: Structure of Tim Anderson Inkjet 3D Printer

3.3 Mechanical parameter distribution and inkjet output control model of 3D printer structure

On the basis of analysing the working principle of 3D printer structure, the mechanical parameter allocation and inkjet output control model of 3D printer structure and the mechanical parameter distribution of 3D printer structure are designed, as shown in Figure 3.

The mechanical parameter allocation and inkjet output control of 3D printer structure should first determine the storage space needed by variables and arrays, as well as the interrupt resources needed (Guo et al., 2017a; Kim et al., 2018). There are many forms of stacking thin layer of 3D printer. In this paper, the liquid plastic material spraying method is used to make the printed object have better three-dimensional characteristics. In this process, in order to improve the printing efficiency and speed, the basis is to realise the mechanical parameter distribution and inkjet output control of 3D printer structure. The mathematical model design is described as follows:

Assuming that Y is the mechanical parameter assignment and inkjet output control dependent variable of 3D printer structure, $X_1, X_2, \ldots, X_{m-1}$ is $m-1$ independent variable with autocorrelation to G, and there is a linear relationship between mechanical parameter assignment and inkjet output control parameter of surface 3D printer:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \cdots \beta_{m-1} X_{m-1} + e \tag{16}$$

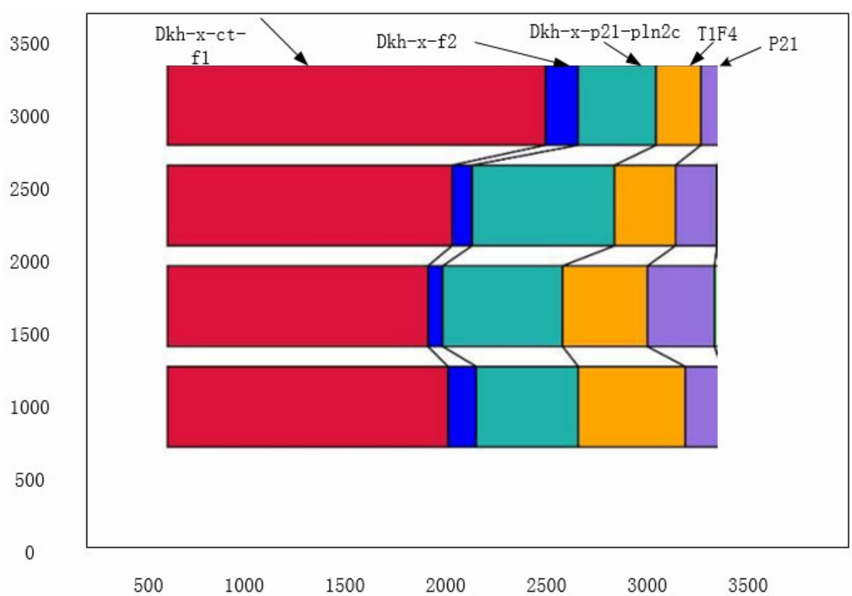
Wherein e is the 3D printing mechanical parameter assignment and inkjet output control inter-circuit interference error term, which represents the influence of interference factors on β besides independent variables and the inertia error of stacked thin layer. Assuming that the spectrum of each signal overlaps, the mechanical parameter allocation of 3D printer and the observed values of inkjet output control signal group are as follows:

$$\left(x_{i1}, x_{i2}, \cdots, x_{i,m-1}\right), i = 1, 2, \cdots, n \tag{17}$$

The resolution of the three-dimensional printer meets the following requirements:

$$\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{pmatrix} = \begin{pmatrix} 1 & x_{11} & \cdots & x_{1,m-1} \\ 1 & x_{21} & \cdots & x_{2,m-1} \\ \vdots & \vdots & & \vdots \\ 1 & x_{n1} & \cdots & x_{n,m-1} \end{pmatrix} \begin{pmatrix} \beta_0 \\ \beta_1 \\ \vdots \\ \beta_{m-1} \end{pmatrix} + \begin{pmatrix} e_1 \\ e_2 \\ \vdots \\ e_n \end{pmatrix} \tag{18}$$

Figure 3 Mechanical parameter allocation of 3D printer structure (see online version for colours)



The resolution error term of 3D printer satisfies Gaussian stochastic process (Guo et al., 2017b; Cataldo et al., 2018). Then the mechanical parameter allocation and inkjet output control model of 3D printer structure is rewritten into matrix form:

$$\mathbf{Y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{e} \tag{19}$$

Wherein **Y** is the mechanical parameter assignment and inkjet output control observation vector of $n \times 1$ 3D printer, and **X** is the printing array matrix of 3D printing of $n \times m$. The stability region of the output torque change of the 3D printer is the reliability control price constraint condition of the 3D printer structure, and the global optimal solution is obtained to realise the optimisation of the decoupling control of the 3D printer structure.

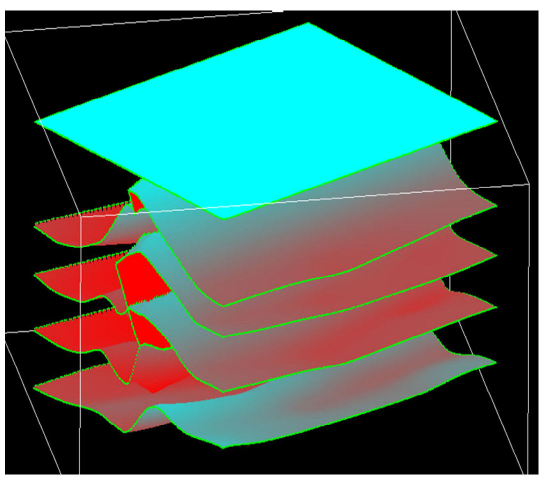
4 Simulation experiment

In order to test the application performance of this method in realising decoupling control of 3D printer structure and automatic estimation of mechanical parameters, the experimental control algorithm is designed by Visual C and Matlab.

4.1 Experimental environment

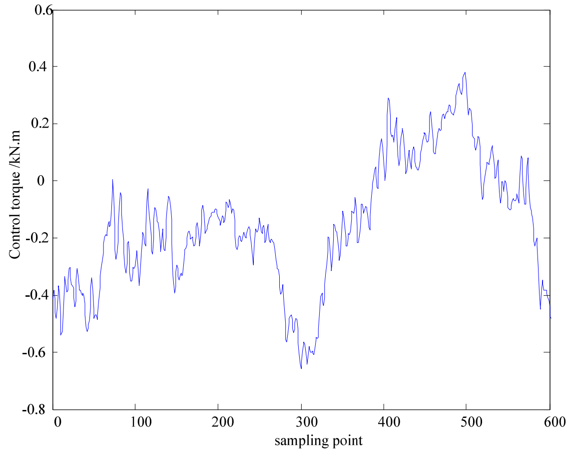
The length of vertical arm rod of 3D printer is set to 4.2 m, the number of mechanical structure components of printer is 3, and the sampling time of mechanical data of printer mechanical structure component is 12 s. The configuration parameter of 3D printer structure is 1.24, the controller is DSpace1103, according to the above simulation environment and parameter setting, the control simulation of 3D printer structure is carried out, and the layer structure of 3D printing is tested as shown in Figure 4.

Figure 4 Layer structure of 3D printing (see online version for colours)



After analysing the original data and output target of plane reconstruction, the acquisition results of mechanical parameters of printer mechanical structure components are shown in Figure 5.

Figure 5 Acquisition results of mechanical parameters of mechanical structure components of printer (see online version for colours)



4.2 Experimental methods

1 According to the data acquisition results of Figure 5, the 3D printer structure position adjustment is carried out. the stability domain of the 3d printer output torque change is used as the reliability control price constraint of the 3D printer structure to obtain the global optimal solution and realise the optimal control of the 3D printer structure.

2 In order to test the performance of the 3D printer structure control performance optimisation algorithm designed in this paper to improve the speed and efficiency of 3D printing, taking the running time and memory consumption of each printing task as the test quantification index, the simulation experiment is carried out.

4.3 Experimental results

1 The control convergence curve is obtained as shown in Figure 6.

2 The calculation results of different methods are shown in Tables 1 and 2, the analysis results can be seen, and the algorithm in this paper is adopted. Can greatly reduce printing time and memory overhead, improve printing speed.

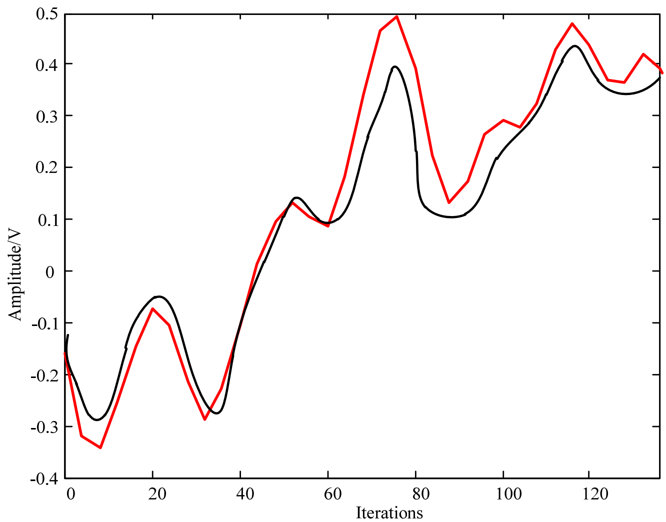
Table 1 Run time (unit: ms)

Test object	*Mackay et al. (2017)*	*Wu et al. (2017)*	*Proposed method/s*
Print out task 1	14,564	5,545	234
Print out task 2	34,356	3,564	556
Print out task 3	65,675	1,567	164
Print out task 4	75,445	5,434	546
Print out task 5	15,448	7,245	1,435
Print out task 6	2,567	1,567	2,567

Table 2 Memory consumption (unit: M)

Object	*Mackay et al. (2017)*	*Wu et al. (2017)*	*Proposed method/s*
Print out task 1	3.667	0.675	0.012
Print out task 2	3.455	0.543	0.030
Print out task 3	3.788	0.232	0.032
Print out task 4	7.900	0.345	0.034
Print out task 5	12.098	0.677	0.067
Print out task 6	4.5656	0.889	0.182

Figure 6 Control convergence curve (see online version for colours)



4.4 *Analysis and discussion of results*

1 In Figure 6, the red line represents the convergence effect of the three-dimensional printer structure control in this method, and the black line represents the standard effect. The analysis of Figure 6 shows that the convergence effect of the three-dimensional printer structure control using this method is close to the standard level, which shows that the three-dimensional printer structure control convergence of this method is good.

2 The experiment adopts the structure of Tim Anderson inkjet 3D printer. By using this method, the quantitative index of desktop 3D printer structure can be effectively evaluated, the interference spectrum of each print input signal can be reduced, and the printing speed can be improved.

5 Conclusions

In this paper, the decoupling control method of 3D printer structure is studied to improve the mechanical automatic distribution ability of printer mechanical structure components. In this paper, a 3D printer structure decoupling control method based on decoupling parallel is proposed, and the linear decoupling method is used to adjust the stable position of the printer mechanical structure components of 3D printer structure. The mechanical parameter allocation and error correction of 3D printer structure damping unit and spring unit are carried out by using high resolution print structure parameter feedback tracking fusion method. The decoupling control law of 3D printer structure is designed under decoupling parallel. The stable region of 3D printer output torque change is the reliability control price constraint condition of 3D printer structure, and the global optimal solution is obtained, and the optimisation of 3D printer structure decoupling control is realised. It is found that the proposed method has good stability, strong convergence and good robustness in 3D printer structure decoupling control.

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