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Research Article

A Financial Chaotic System Control Method Based on Intermittent Controller

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Finance is the core of modern economy. The security and stability of the financial system is the key to stable economic and social development. During the operation of the financial system, financial chaos such as the severe turbulence of the financial market and the financial crisis occurred due to deterministic instability, which brought a great negative impact on economic growth and social stability. For the financial chaotic system, an intermittent feedback controller is designed in this paper. By adjusting the controller parameters, the financial system can be controlled from chaotic to periodic evolution. First, the dynamic equations and controllers of the financial system are analyzed and the range of values of the controller parameters is theoretically obtained. Then, the influence of parameters on the system is studied, and the feasibility of the proposed method is proved by numerical simulation. Finally, the practical significance of the controller on the macrocontrol of the financial crisis is discussed. It is theoretically proven that when the financial crisis comes, the financial system can be stabilized more quickly through appropriate control methods.

1. Introduction

Chaos is a random, seemingly irregular motion produced by a deterministic nonlinear dynamic system [1]. In the past two to three decades, approximation methods, numerical integration methods of nonlinear differential equations, and especially the rapid development of computer technology have been provided the possibility for in-depth research on chaos. The study of chaos theory has also enabled people to more fully and thoroughly understand and apply chaos [2–9]. In recent years, it is a hot issue of the application of nonlinear dynamics in financial chaos models [10–14], in view of whose nonlinear evolution occurs in many aspects of financial markets. In particular, the financial system is interfered by uncertainties in the market environment. Therefore, it is more feasible to describe the financial chaos model with random factors.

Chaos economics, also known as nonlinear economics, is an emerging discipline in the 1980s that applied nonlinear chaos theory to explain real economic phenomena. Compared with traditional economics, chaotic economics is fully considered the nonlinear interaction of economic activities in economic modeling. In the analysis of models, the theory and method of bifurcation, fractal, and chaos of nonlinear dynamics are also fully utilized. It is also fully utilized the theory and method of bifurcation, fractal, and chaos of nonlinear dynamics. Unlike traditional economics, it is believed that time is irreversible; with the evolution of time, the system always has a new state of affairs, never repeated, whose connection between cause and result is not unique, but a cyclic causal relationship [15]. In traditional economics, unstable fluctuations have always been regarded as unfavorable phenomena. For a long time, because chaos means some unpredictable events, chaos is often harmful to policy makers in the economic field. Due to the initial value sensitivity of chaotic motion and the unpredictability of long-term development trend, how to control chaos has become a key link in the application of chaos in the economic field. The emergence of nonlinear economics, especially chaotic economics, has led to dramatic changes in the study of economics. Chaos theory provides us with an important analytical tool [16–18]. Important dynamics such as attraction, bifurcation, mutation, and chaos of complex economic systems can be analyzed by using dynamic nonequilibrium methods. Therefore, this can achieve control of certain chaotic phenomena in the economic field or reveal certain laws hidden behind complex economic phenomena.

In 1980, the American economist Stutzer [19] first revealed the chaotic phenomenon of the macroeconomic system in the Haavelmo economic growth equation, which made people aware of the limitations of economic models based on traditional economic theories and to apply chaotic models to economics at the earliest [20, 21]. In [22], the global exponential attracting set and synchronization problem of many financial systems are studied by using the definitions of the global exponential attracting set and Lyapunov stability theory. In [23], the global asymptotic synchronization strategy of three-dimensional chaotic financial systems is studied by using Lyapunov stability theory and Routh–Hurwitz criterion. In [24], numerical simulation is used to analyze the equilibrium, stability, chaotic attractor, Lyapunov exponent, and bifurcation of chaotic financial systems. In [25], the reparameterization model with evaluation parameters in macroeconomics is studied, the method of which is equivalent to the standard.

Since 20th century, the global financial crisis has erupted. In order to reveal the development law of financial markets, people have explored the internal structure of the financial system through the establishment of financial mathematical models, revealed the chaotic state existing in the financial system, and tried to use various methods to control to restore the financial market to normal order. Chaos control refers to the control and induction of the chaotic state, artificially affecting the chaotic system to develop it into the actual state. In 1996, J.A.Holyst published “How to Control the Chaos Economy,” which pioneered the study of economic chaos control. In recent years, many scholars have proposed a variety of economic chaos control methods and achieved certain achievements. Kopel [26] uses the chaotic target method to control chaos of a monopoly output adjustment model. Hołyst and Urbanowicz [27] use the delayed feedback control method (DFC) to control chaos in a duopoly investment model. Wieland and Westerhoff [28] applies the OGY method and DFC separately to stabilizing chaos in an exchange rate dynamic model. In [29], the method of phase space compression control chaos is applied to economic systems. In [30], the authors investigate the stability conditions in a fractional-order financial system using the fractional Routh–Hurwitz criteria. Furthermore, the fractional Routh–Hurwitz conditions are used to control chaos in the proposed fractional-order system to its equilibria via the linear feedback control method. Kai et al. [31] introduce a new four-dimensional hyperchaotic financial system on the basis of an established three-dimensional nonlinear financial system and a dynamic model by adding a controller term to consider the effect of control on the system. In [32], the system of integer and fractional differential equations is applied to model the financial system, and the control law is designed to synchronize two integer-order financial systems and two fractional-order financial systems.

Stability is the foundation of financial development. By establishing a mathematical model to analyze the combination of financial stability, not only can it help the macrocontrol of the financial system but also help the mitigation of the financial crisis through the study of the financial chaotic system control model. In recent years, significant progress has been made in the field of control [33–40]. Control algorithms have emerged endlessly, which have created favorable conditions for financial chaos control. This paper designs an intermittent feedback controller. By adjusting the controller parameters, the financial system can be evolved from chaos to period. In Section 2, the paper describes the financial system dynamics equation and the intermittent controller. The dynamics of the financial chaotic system is analyzed in Section 3. Then, the influence of the parameter change on the financial chaotic system is analyzed in Section 4. Finally, the conclusion is summarized.

2. Mathematical Description of the Financial System

2.1. Dynamic Equations of the Financial System. Inspired by the literature [41–44], the financial system consists of four submodules: production, capital, shares, and labor. The system describes the temporal changes of four state variables: interest rate$x$, investment needs$y$, price index$z$, and average profit margin$u$. Therefore, the following equation is given for the financial system:

$$\begin{cases} \dot{x} = z + (y - a)x + u, \\ \dot{y} = 1 - by - x^2, \\ \dot{z} = -x - cz, \\ \dot{u} = -dx\,y - \lambda u, \end{cases} \tag{1}$$

where the amount of storage is$a$, b is the investment growth rate, and c is the supply and demand coefficient. The parameters d and λ are positive coefficients.

2.1.1. The Existence of Attractors. The divergence of system (1) is

$$\nabla V = \frac{\partial x^2}{\partial x} + \frac{\partial y^2}{\partial y} + \frac{\partial z^2}{\partial z} + \frac{\partial y^2}{\partial u} = -(a + b + c + \lambda). \tag{2}$$

Therefore, when$a + b + c + \lambda > 0$, it is known that system (1) is a dissipative system, and the phase volume of the system shrinks at an exponential rate $dv/dt = e^{-(a+b+c+\lambda)}$. As $t \longrightarrow \infty$ changes, the trajectory of the system gradually evolves into a constant set of attractors, which indicates the existence of attractors.

2.1.2. The Balance Point of the System:. When the parameters$a, b, c, d,$ andλ satisfy$(\lambda b + dc + abc\lambda - c\lambda/c(d - k)) > 0$, system (1) has three equilibrium points:

$$p_{01}\left(0,\frac{1}{b},0,0\right),$$

$$p_{02}\left(\gamma,\frac{\lambda+ac\lambda}{c(\lambda-d)},-\frac{\gamma}{c},\frac{d\gamma(1+ac)}{cd-c\lambda}\right), \tag{3}$$

$$p_{03}\left(-\gamma,\frac{\lambda+ac\lambda}{c(\lambda-d)},\frac{\gamma}{c},\frac{d\gamma(1+ac)}{cd-c\lambda}\right),$$

where $\gamma=\sqrt{\lambda b+abc\lambda/c(d-\lambda)+1}$.

2.2. Description of the Intermittent Controller of the Financial Chaotic System. The operation of financial markets is very complicated. When financial markets are volatile or financially crises, they must be regulated in a timely manner to maintain the stability of the financial market. An intermittent controller is designed to meet the regulatory requirements of financial fluctuations in this paper:

$$\begin{cases}\dot{x}=z+(y-a)x+u+g,\\ \dot{y}=1-by-x^2,\\ \dot{z}=-x-cz,\\ \dot{u}=-dxy-\lambda u.\end{cases} \tag{4}$$

In this article, g is the controller:

$$g=0.5*\lambda*\left[\left|\sin(x-x_e)\right|+\sin(x-x_e)\right], \tag{5}$$

where λ adjusts the parameter and also the parameter in equation (1)fd1 and x_e is the equilibrium point. When the financial system fluctuates and the chaotic state appears, control begins to play a regulatory role.

In the following, the system stability analysis will be demonstrated in detail.

Theorem 1. *For control model (5), when*$\lambda_2<\lambda<\lambda_1$, *system (4) is a large range of progressive stability at the equilibrium point*$p_1(0,1/b,0,0)$.

Here,

$$\lambda_1=\frac{c(1-b^2)+\left[a^2b^2c^2+2ab^6c-2ab^5c^2+2ab^3+b^6+4b^5c^2d+2b^5c+b^4c^2+2b^3c-2b^2c^2+c^2\right]^{1/2}+b^3+ab^3c}{2b^3c},$$
$$\lambda_2=\sqrt{ab+(a^2b^2-2ab+b^2+1)+1/2b}. \tag{6}$$

Proof. The balance point of the computational model (4) is available; when $\lambda_0<\lambda<\lambda_1$,

$$\lambda_1=\frac{c(1-b^2)+\left[a^2b^2c^2+2ab^6c-2ab^5c^2+2ab^3+b^6+4b^5c^2d+2b^5c+b^4c^2+2b^3c-2b^2c^2+c^2\right]^{1/2}+b^3+ab^3c}{2b^3c},$$
$$\lambda_0=\frac{c(1-b^2)+\left[a^2b^2c^2+2ab^6c-2ab^5c^2+2ab^3+b^6+4b^5c^2d+2b^5c+b^4c^2+2b^3c-2b^2c^2+c^2\right]^{1/2}+b^3+ab^3c}{2b^3c}. \tag{7}$$

It should be noted that due to$x\longrightarrow 0$, we think that $\sin x\approx x$ is suitable.

System (4) has a unique equilibrium$p(0,1/b,0,0)$.

So, the Jacobi matrix at equilibrium point $p(0,1/b,0,0)$ is

$$J=\begin{bmatrix}\frac{1}{b}-a+\lambda & 0 & 1 & 1\\ 0 & -b & 0 & 0\\ -1 & 0 & -c & 0\\ 0 & 0 & 0 & -\lambda\end{bmatrix}. \tag{8}$$

According to the Krasovsky rule, there is

$$-Q(t)=J(t)+J^T(t). \tag{9}$$

So, $Q(t)$ can be obtained:

$$Q(t)=\begin{bmatrix}\frac{2}{b}+2a+2\lambda & 0 & 1 & 1\\ 0 & 2b & 0 & 0\\ 0 & 0 & 2c & 0\\ -1 & 0 & 0 & 2\lambda\end{bmatrix}. \tag{10}$$

According to the Sylvester criterion, when

$$\Delta_1 = \begin{vmatrix} \frac{2}{b} + 2a - 2\lambda & 0 & -1 & -1 \\ 0 & 2b & 0 & 0 \\ 0 & 0 & 2c & 0 \\ -1 & 0 & 0 & 2\lambda \end{vmatrix} > 0,$$

$$\Delta_2 = \begin{vmatrix} 2b & 0 & 0 \\ 0 & 2c & 0 \\ 0 & 0 & 2\lambda \end{vmatrix} > 0, \qquad (11)$$

$$\Delta_3 = \begin{vmatrix} 2c & 0 \\ 0 & 2\lambda \end{vmatrix} > 0,$$

$$\Delta_4 = |2\lambda| > 0,$$

the system is gradually stable over a wide range of equilibrium points.

So, after calculation $\lambda > \lambda_2 \cdot \lambda_2 = \sqrt{ab + (a^2b^2 - 2ab + b^2 + 1)} + 1/(2ab)$.

In summary, when $\lambda_2 < \lambda < \lambda_1$, system (4) is a large range of progressive stability at the equilibrium point $p_1\,(0, 1/b, 0, 0)$. □

3. Financial System Dynamics Analysis

After the design of the financial system, mathematical analysis and numerical simulation are needed to analyze their dynamic characteristic, which proves that the model is a chaotic map and at the same time explains the existence of periodic and chaotic motion in the financial system. At present, the commonly used chaotic recognition methods are the phase diagram method, spectrum analysis method, Poincare mapping method, K-entropy method, and Lyapunov exponent method. However, these chaotic identification methods have certain adaptation scope and limitations. For example, the phase diagram method is simple and intuitive, but the accuracy is not high. The spectrum analysis method is difficult to distinguish the motion patterns from the spectrum affected by the noise. Poincaré mapping method cannot distinguish chaos and completely random motion; the calculation result of the largest Lyapunov exponent method is not directly obtained, and the determination of delay time and embedding dimension have certain subjectivity and uncertainty.

Recently, Gottwald G A and Melbourne I [45, 46] proposed a reliable and efficient binary method for checking whether a system has chaos, called "0–1 test." The method can determine whether the current system is chaotic by whether the asynchronous growth rate and the dynamic system reconstructed by the discrete data are unbounded motions. The 0-1 test method is a means that does not require phase space reconstruction and directly determines whether the chaos exists by calculating whether the linear growth rate K_c value of the discrete data transformation variable approaches 1 or 0.

In this paper, 0-1 test is used for system dynamics analysis. First, any positive number $c \in [\pi/5, 4\pi/5]$ is selected, and use the numerical simulation data to form a discrete set $\{\Phi(j)\}\,(j = 1, 2, \ldots, N)$; generally take n not more than 0.1 times the length N of the discrete set and define a conversion variable of the form:

$$p_c(n) = \sum_{i=1}^{n} \phi(i) \cos ic, q_c(n) = \sum_{i=1}^{n} \phi(i) \sin ic. \qquad (12)$$

In order to quantify the growth characteristics (such as diffusion behavior) of the characterization functions $p_c(n)$ and $q_c(n)$, the mean square displacements of $p_c(n)$ and $q_c(n)$ are defined (Mean Square Displacement, MSD, $M_c(n)$) as follows:

$$M_c(n) = \lim_{N\longrightarrow\infty} \left\{ \sum_{i=1}^{N} \left[p_c(i+n) - p_c(i)^2 \right] + \left[q_c(i+n) + q_c(i) \right]^2 \right\} - \left[\lim_{N\longrightarrow\infty} \frac{1}{N} \sum_{i=1}^{N} \Phi(i) \right]^2 \frac{1 - \cos nc}{1 - \cos c}. \qquad (13)$$

The convergence of functions $p_c(n)$ and $q_c(n)$ can be measured by $M_c(n)$. The progressive growth rate K_c of $M_c(n)$, that is, the chaotic characteristic index of the dynamic system can be obtained by linear regression of $\log M_c(n)$ and $\log n$, or by the correlation coefficient of both.

The algorithm steps are as follows:

(1) Use data points of the system to form a discrete set $\phi(N)$.

(2) Take one data point every 8 data points instead of the discrete set $\Phi(N)$.

(3) Bring $\Phi(N)$ into the transformation variable to obtain $p_c(n)$ and $q_c(n)$ and display it as the trajectory image of $p_c(n) q_c(n)$.

(4) From $p_c(n)$ and $q_c(n)$, the image of the mean square displacement $M_c(n)$ varies with n and the progressive growth rate K_c of $M_c(n)$.

(5) Take the median of all K_c as the median value of K. When K tends to 1, the discrete set $\Phi(N)$ exhibits chaotic characteristics. When K approaches 0, the discrete set $\Phi(N)$ exhibits nonchaotic characteristics.

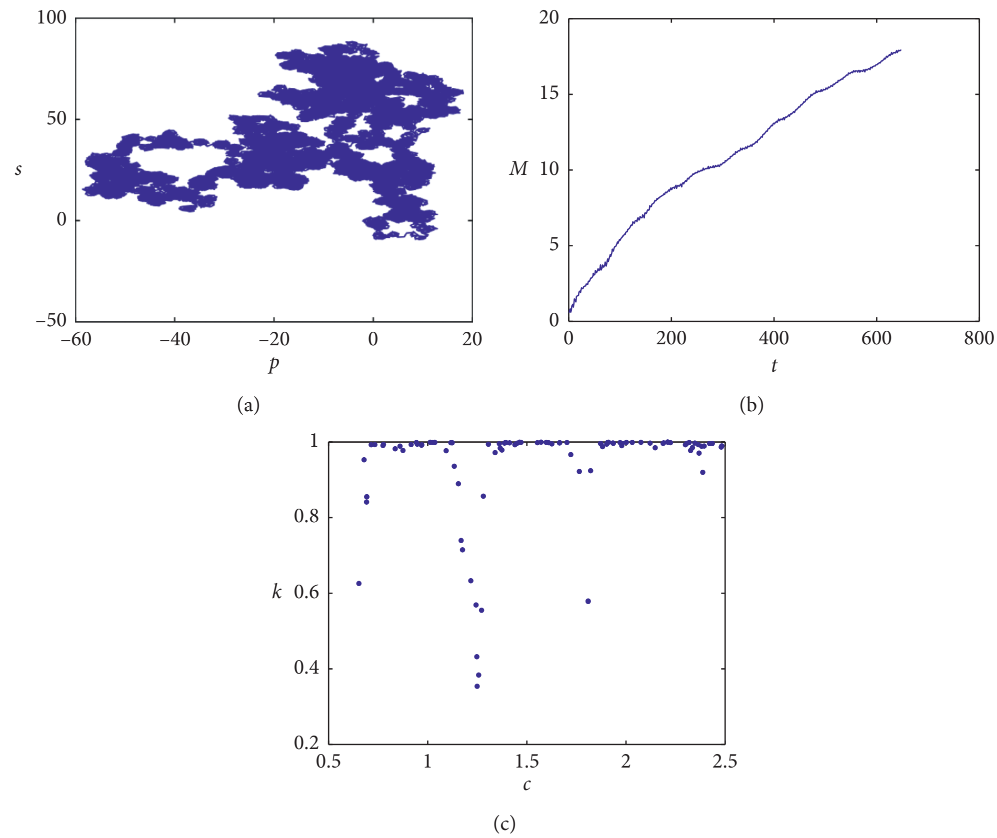

Figure 1: Financial system without the controller: (a) *s*-*p* trajectory map, (b) *M (n)*-*n* map, and (c) *K (c)*-*c* scatter plot.

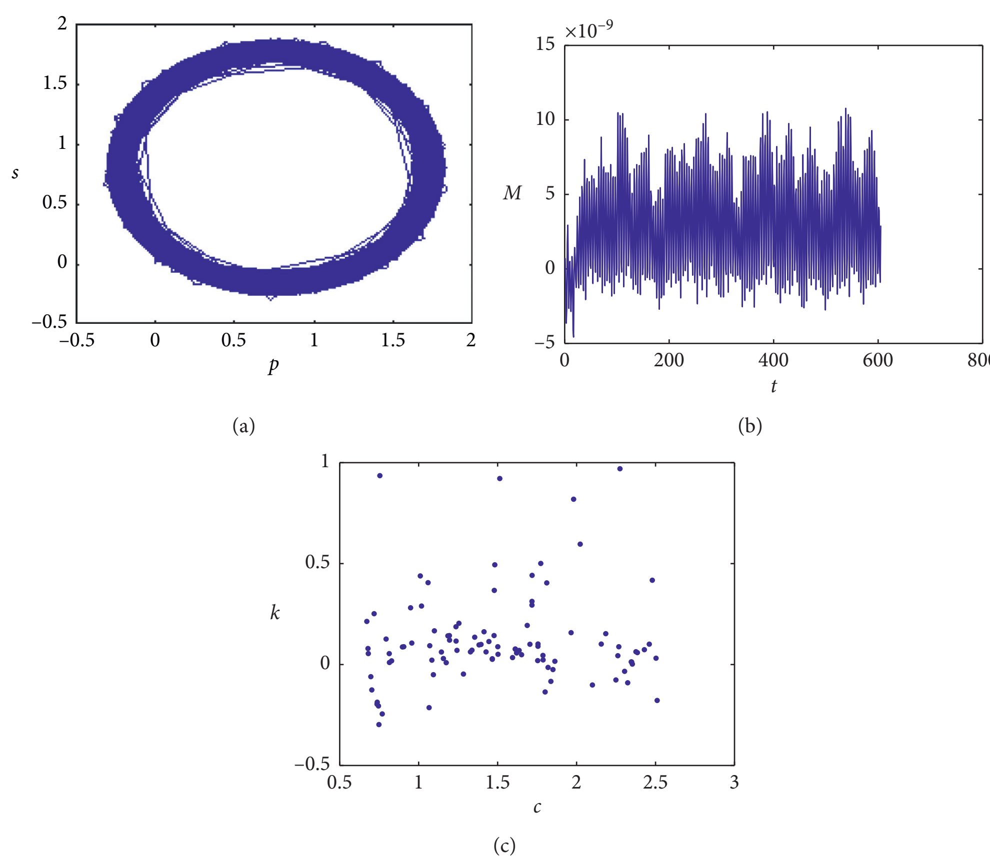

Figure 2: Financial system after adding the controller: (a) *s*-*p* trajectory map, (b) *M (n)*-*n* map, and (c) *K (c)*-*c* scatter plot.

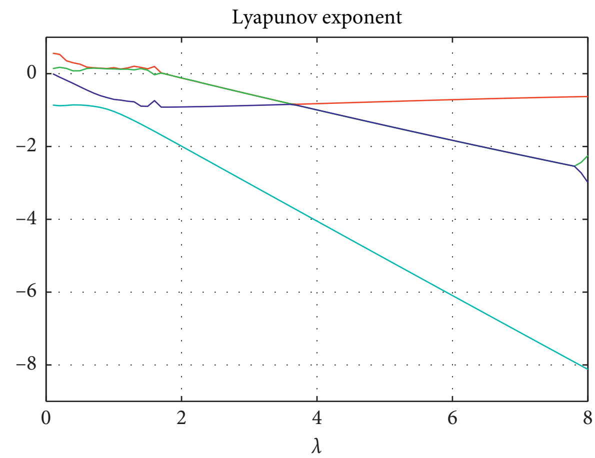

Figure 3: Lyapunov exponential change graph for parameter λ change.

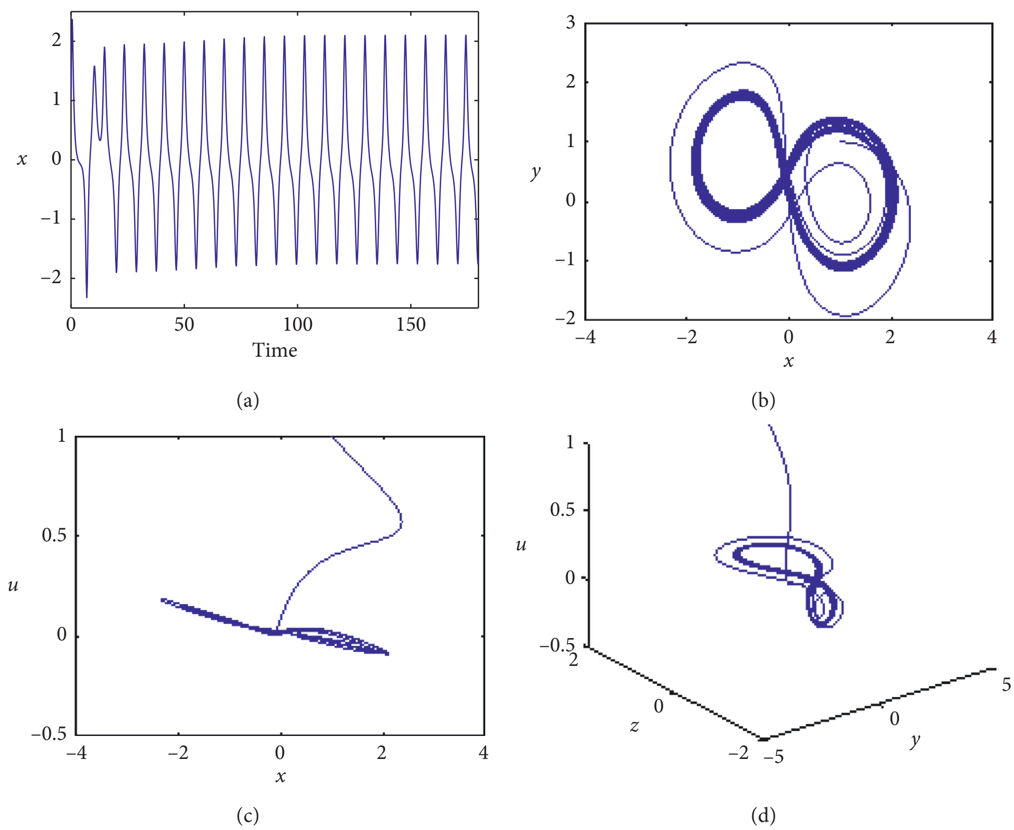

Figure 4: Phase diagram of the system when $\lambda = 1$: (a) x-t; (b) x-y; (c) x-u; (d) y-z-u.

Judgment rule: it can be seen from the literature that if the graph presents a random Brownian motion pattern, $M_c(n)$ grows linearly with time and K is close to 1, it is judged as a chaotic time series; if the $p_c(n) - q_c(n)$ graph presents a bounded periodic ring, $M_c(n)$ is bounded, and K is close to 0, it is judged to be a nonchaotic time series (periodic or doubling period). Since c may generate frequency resonance with the Fourier decomposition of the time series during the calculation, the limit c is $\pi/100$ random numbers between $\pi/5$ and $4\pi/5$. The final return value is the median of all K_c.

Before and after the controller is added, the 0-1 test is used to identify whether the financial system is chaotic, and the phase diagram method is used to analyze the system state in this paper.

3.1. Financial System before the Controller Is Added. When $a = 0.1, b = 0.1, c = 1.2$, and $d = 0.1$, the 0-1 test of the uncontrolled financial system (1) shows that the median $K(c)$ of the four-dimensional system is 0.9923 (confirmed as "1"), 0.9948 (confirmed as "1"), 0.9961 (confirmed as "1"),

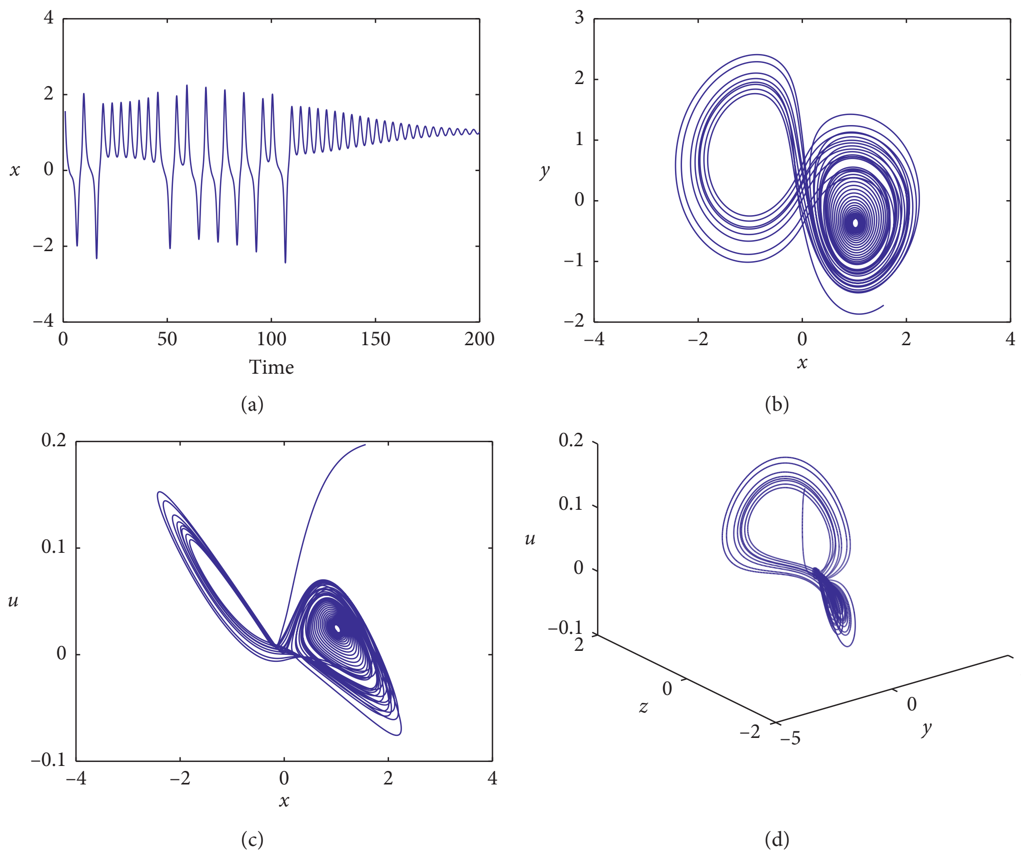

Figure 5: Phase diagram of the system when $\lambda = 1.53$: (a) x-t; (b) x-y; (c) x-u; (d) y-z-u.

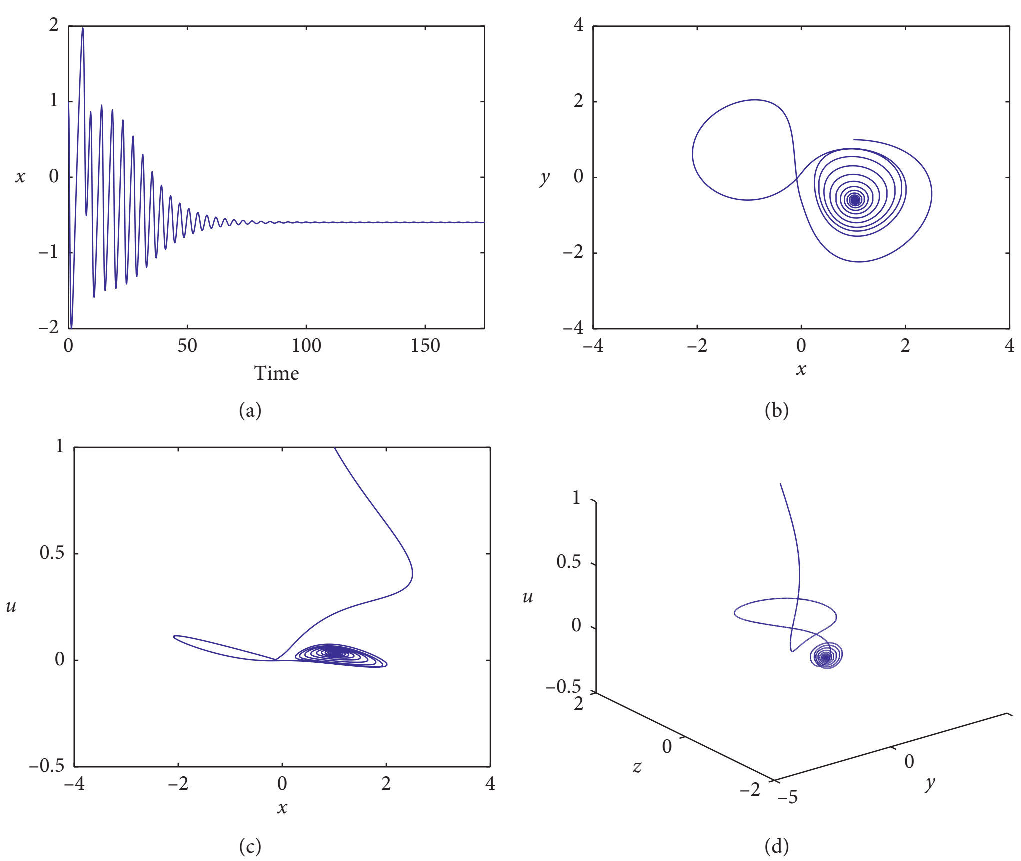

Figure 6: Phase diagram of the system when $\lambda = 1.8$: (a) x-t; (b) x-y; (c) x-u; (d) y-z-u.

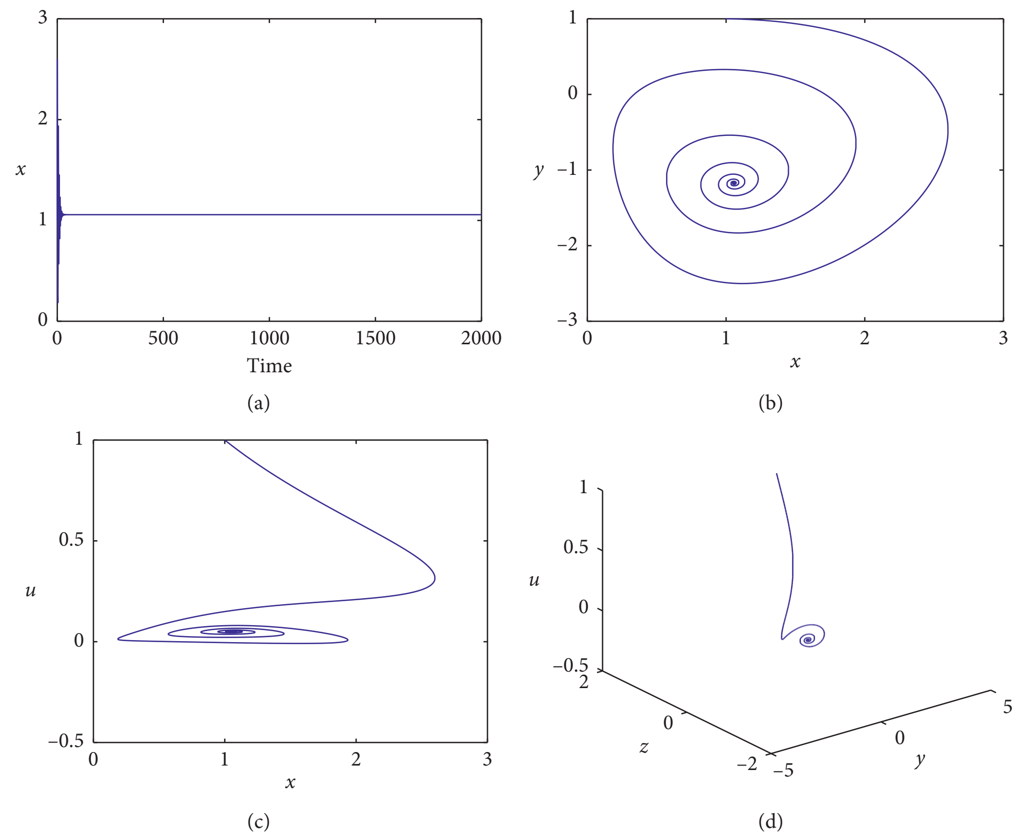

Figure 7: Phase diagram of the system when $\lambda = 2.5$: (a) x-t; (b) x-y; (c) x-u; (d) y-z-u.

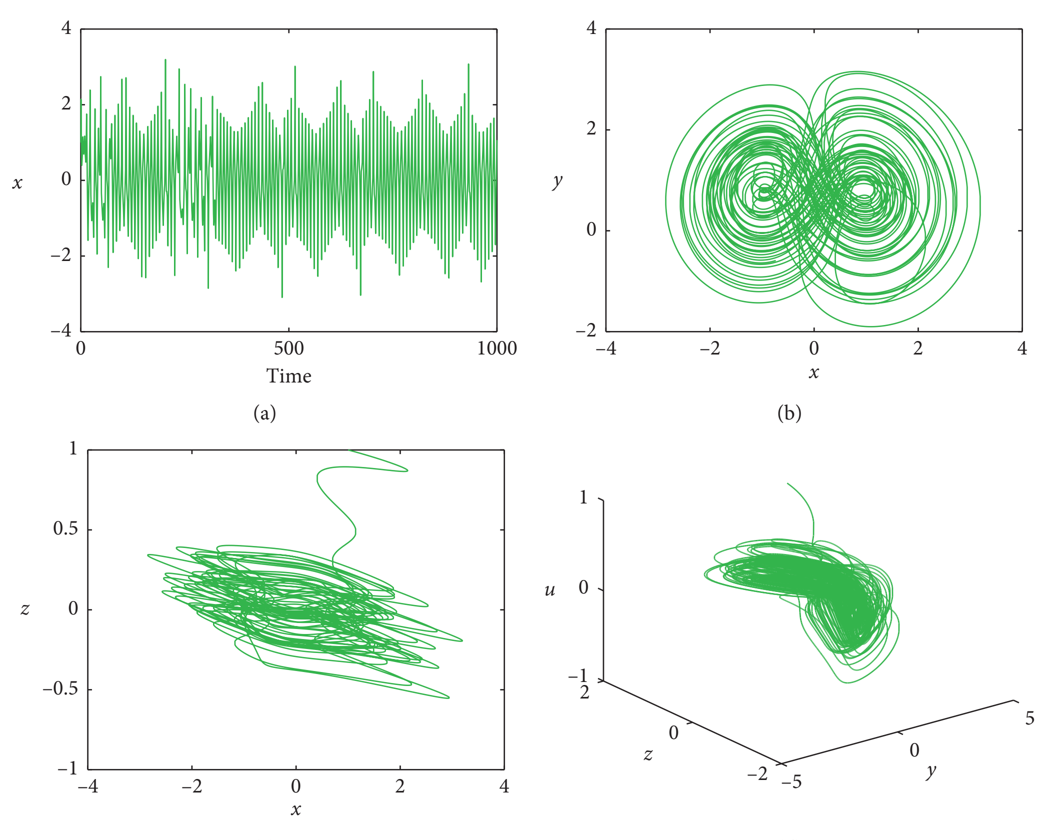

Figure 8: Phase diagram of the system when $\lambda = 0.15$: (a) x-t; (b) x-y; (c) x-u; (d) y-z-u.

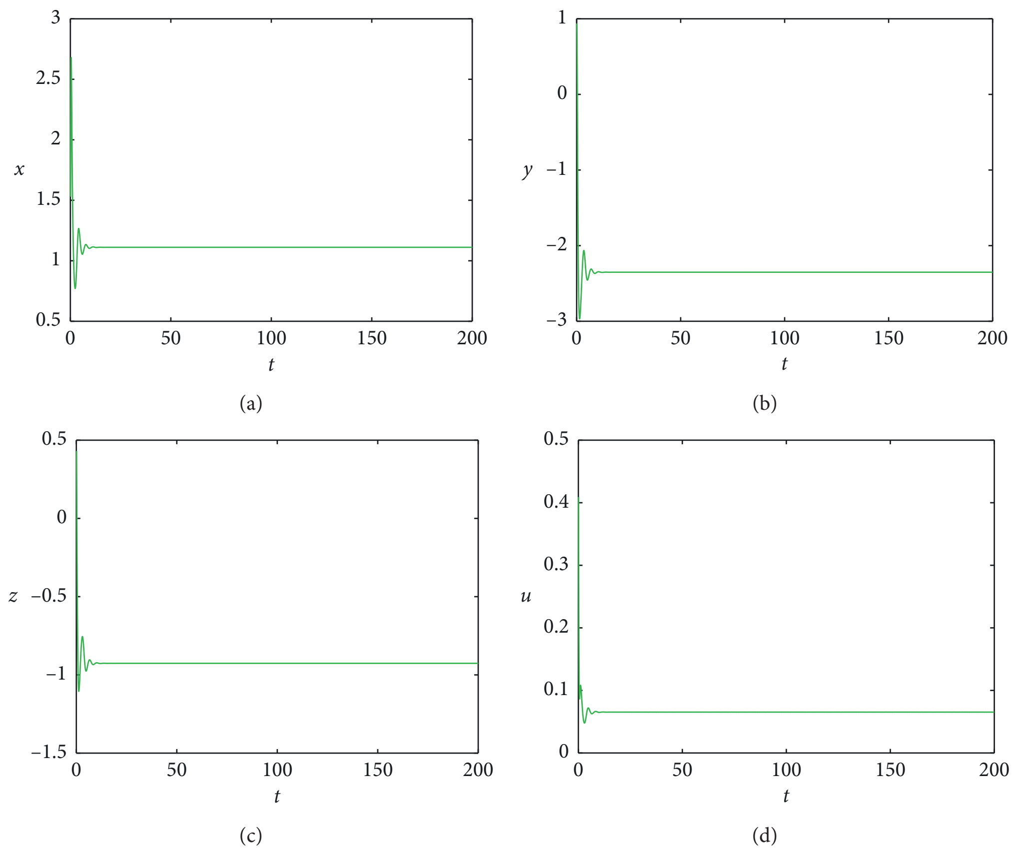

Figure 9: The state variable of the system as a time curve: (a) x-t; (b) y-t; (c) z-t; (d) u-t.

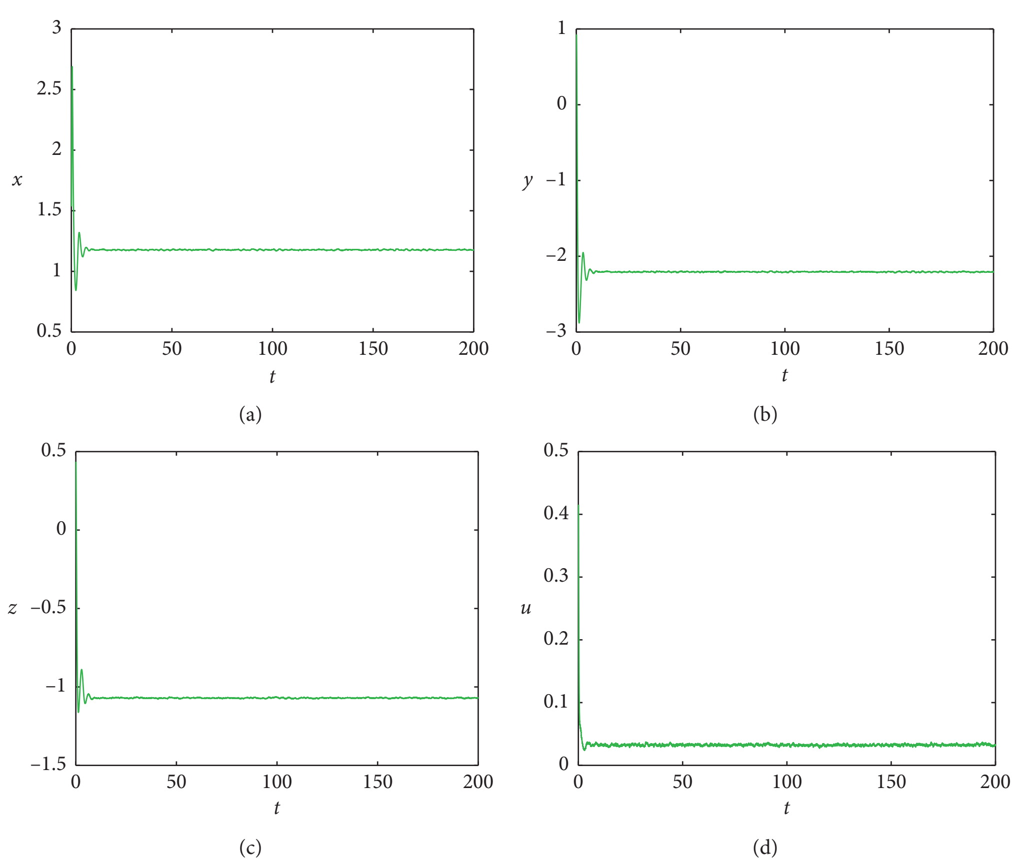

Figure 10: The state variable of the system after disturbance is added to the time curve when $\lambda = 0.15$ is added: (a) x-t; (b) y-t; (c) z-t; (d) u-t.

and 0.9873 (confirmed as "1"). Figure 1 shows the $s-p$ trajectory map, $M(n)-n$, and $K(c)-c$ scatter plots for the phase diagram of the financial system without the controller. In this paper, only the second-dimensional data is given. The $p(t)$-motion shown in Figure 1 is an unbounded motion similar to the Brownian motion. The $M(n)$ generally increases with the increase of n, and K_c mostly concentrates around 1. It can be proved. This system is chaotic.

3.2. Add Controller to the Financial System. When $a = 0.1, b = 0.1, c = 1.2, d = 0.1$, and $\lambda = 2.5$ and the 0-1 test of Section 2.2 after the controller is added, the median *Kc* of the four-dimensional financial system is −0.0387 (confirmed as "0"), 0.0564 (confirmed as "0"), 0.0607 (confirmed as "0"), and 0.0543 (confirmed as "0"). After adding the controller, Figure 2 shows the *s-p* trace map corresponding to the phase diagram of the financial system and *M-n* and *K-c* scatter plots. In this paper, only the graph of the second-dimensional data is given. It can be seen from Figure 2 that the motion of $p(t)$ is a bounded periodic loop, $M(n)$ is bounded, and K_c is mostly concentrated near 0, which proves that the system is nonchaotic.

4. The Impact of Parameter λ Changes on the System

In the control system (4), the parameter λ is both a system coefficient and a controller adjustment parameter, which plays a key role in system changes. Based on this, in order to better study the control effect of the controller, $a = 0.1, b = 0.1, c = 1.2$, and $d = 0.1$ is maintained in this paper, and the influence of the change of the controller parameter λ on the system is mainly studied. Figure 3 shows the Lyapunov exponent of the parameter λ. It is obvious from the figure that after adding the controller, as the controller parameter λ grows, the maximum Lyapunov exponent also changes, and the system gradually becomes orderly.

4.1. When $\lambda = 1$. When $\lambda = 1$, as the control of the controller is strengthened, the system completes a periodic state. Figure 4(a) shows periodic up and down oscillations, the amplitudes are almost equal and relatively large, and Figures 4(b)–4(d) show typical periodic motion.

4.2. When $\lambda = 1.53$. When $\lambda = 1.53$, as the control of the controller is strengthened, the system completes a periodic state. Figure 5(a) shows periodic up and down oscillations, but the amplitude is decreasing, and Figures 5(b)–5(d) show typical periodic motion.

4.3. When $\lambda = 1.8$. When $\lambda = 1.8$, as the control force of the controller is further strengthened, the graph in Figure 6(a) changes from the periodic up and down oscillation state to the slow decay state. As can be seen in Figures 6(b)–6(d), the system gradually converges and finally stabilizes in a small area.

4.4. When $\lambda = 2.5$. As $\lambda = 2.5$, as the control is further enhanced, the attenuation of Figure 7(a) is further evident, converges to 1 in a very short time, but still shows the period for Figures 7(b)–7(d) status.

The abovementioned analysis shows that the controller proposed in this paper has strong control over system (1), which can quickly converge and stabilize at a clear value. At the same time, the system will also tend to be stable.

5. Analysis of System-Added Disturbances

The operation of financial markets is very complicated. When financial markets are volatile or financially crises, they must be regulated in a timely manner to maintain the stability of the financial market. For example, when the financial system parameters are $a = 0.1, b = 0.1, c = 1.2, d = 0.1$, and $\lambda = 0.15$, the system appears chaotic, as shown in Figure 8, which indicates that financial market instability or financial crisis may occur and measures need to be taken in time.

5.1. Trend of Change of State Variables after Adding the Controller System. The method of the regulating interest rate can be used to apply the financial chaotic system intermittent control system (4), which can realize the control of system chaos and achieve the purpose of stabilizing the financial market. It can be seen from the figure that controller (5) starts working immediately, and chaos can be eliminated in a very short time, and the system tends to be in a stable state (Figure 9).

5.2. Change Trend of System State Variables after Disturbance. In the financial market, the storage is a, the investment growth rate is b, and the supply and demand coefficient c are not always constant, which have certain volatility, and we verify the robustness of the designed controller.

Add a disturbance to the system parameters $a = 0.1 - 0.1 * \mu$, $b = 0.1 + 0.15 * \mu, c = 1.2 - 0.2 * \mu$, and $d = 0.1 - 0.1 * \mu$, where μ is any number from 0 to 1. When the system starts, the controller starts working quickly, and the system state variable interest rate x, investment needs y, price index z, and so on change with time, as shown in Figure 10. After the controller starts working, the whole system can still be stable in a short time, indicated that the proposed method has certain robustness.

6. Conclusion

In the modern market economy, the role and status of finance has been becoming increasingly prominent. The security and stability of the financial system is the key to stable economic and social development. However, with financial liberalization and financial globalization, the financial system has become an open and extremely complex nonlinear system. Uncertainty operation from quantitative change to qualitative change caused by destabilization of deterministic operation in the financial system and financial chaos such as severe financial market turbulence, financial crisis, and financial tsunami. The efficiency of resource allocation has brought a great negative impact on economic growth and social stability. According to the basic theory and method of the dynamical system, this paper proposes an intermittent control method for the chaotic phenomenon of the financial system. Firstly, the dynamic analysis of the financial chaotic model is carried out and the value range of the system controller parameters is theoretically analyzed. Then, the influence of parameters on the system is studied, and the feasibility of the proposed method is proved by numerical simulation. Finally, the practical significance of the controller on the macrocontrol of financial crisis is discussed. Therefore, the intermittent controller proposed in this paper has a simple structure, good self-adaptability, and strong robustness and anti-interference ability.

Data Availability

The results in the paper are all implemented by MATLAB simulation, and the chaotic model used to support the findings of the study are available within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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