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Robust Control of a Wafer Stage System by means of Artificial Neural Networks(ANN)

Athira K. H.
Dept. of Electronics and Communication Engineering
Mohandas College of Engineering and Technology
Thiruvananthapuram,India
athirakh93@gmail.com

Dr. K. Prescilla
Dept. of Electronics and Communication Engineering
Mohandas College of Engineering and Technology
Thiruvananthapuram,India
priscilla_koshy@yahoo.com

Abstract— **Manufacturing of integrated circuits (IC's) plays a key rolein electronic industry by means ofa fine slice of crystalline silicon, called wafer. Wafer Scanners are apparatus for the creation ofIC's. In the production process, the wafer must be exactlypositioned. For this reason, data-drivenapproaches are more promisingthan the model based approaches. This data-determined approach avoids the necessity of modeling and enables the direct tuning of the controller based on calculated data.Iterative Feedback Tuning (IFT) is an optimization methodology that aims at conducting multiple experiments without any requisite of a parametric model. IFT has been effectively useful in several applications together with process industry, robotics, servo systems, mechatronics, etc.A significant field of application where data determined controller tuning is appealing is in high-precision motion control. Through IFT, the parameters analyzed are controller settings, robust steadiness using bode plot, the parameter convergence, error minimization and the time-domain response. PID controller tuning using Ziegler – Nichols(ZN) method is used andproportional, integral and derivative gain values are calculated. For a precise mechanical positioning, Artificial Neural Network (ANN) is used.**

IndexTerms—**Lithographic wafer Scanners, Model-based control,Data-driven approaches, Artificial Neural Network (ANN), Feedforward networks.**

I.INTRODUCTION

Wafer manufacturing industries have prolonged been a motivating force behind main advances in electronics. A wafer is an extremely pure, almost fault-free crystalline substance used for the fabrication of integrated circuits.Semiconductor devices are the basis of the electronics industries.Most of the semiconductor devices are built on silicon wafers. A silicon wafer withnumerous semiconductor devices is shown in Figure 1. From the development of silicon ingots, the manufacturing of extreme quality silicon wafers starts. Just a small layer on the surface of a silicon wafer is used for the buildingof electroniccomponents; the rest servesas a base for the mechanical system.

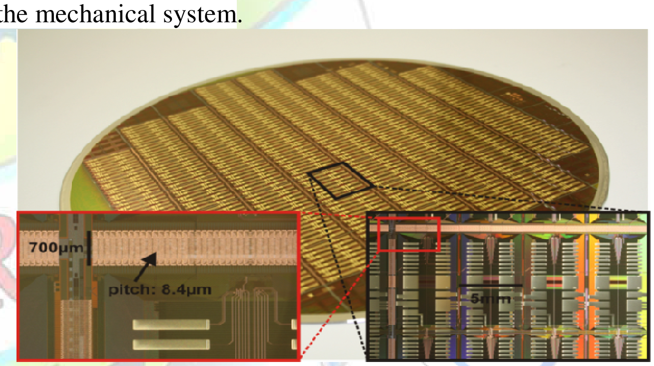

Fig.1. A detailed view of silicon wafer

The typical lithographic equipment has a light source, reticle loading section, reticle stage system, reticle alignment system, lens, wafer loading part, wafer stage system and wafer alignment system. Photolithography is the process of moving the desired circuit pattern from a mask on the reticle stage onto the silicon wafer. Lithographic equipment (or steppers) are exceedingly intricate machines used for the production of ICs. Figure 2 shows the pattern printing procedure in a lithographic scanner. Optical lithography is the commonly used method to make Integrated Circuits.

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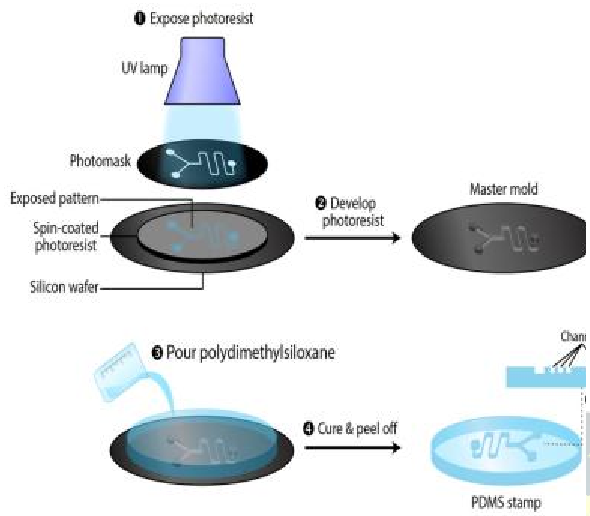

Fig.2. The pattern printing procedure in a lithographic scanner

The light (ultraviolet) from the light source passes the reticle plate which is held in a reticle stage system to the wafer. The light passes the projection lens by means of a projection optics section that forms the desired image on the wafer, which is supported by a wafer stage system.The reticleand the wafer are both movable by a precise positioning mechanical system. Before the exposure, the position of the wafer must be determined as exactly as possible with an automatic alignment system.

Model – based approaches consume much time and it is a difficult process. Data-based controller tuning is appealing in the case of high-accuracy motion control since it avoids the need of modeling and enables direct tuning of the controller. While using Iterative feedback Tuning (IFT), there is no requirement of a parameter or a disturbance model [1]. Each silicon wafer contains greater than 200 ICs which are exposed sequentially. Wafer stage system's precision motion task through a predefined reference trajectory in 6 degrees-of-freedoms (DOFs) is examined. The progress and accomplishment of a joint system identification and strong control design for next-generation motion control are explained [2]. In automation industry and process control, traditional PID (proportional-integral-derivative) controller is extensively applied due to its direct control mode, simplicity in structure and robustness. But the restrictions while using the PID control are its regulatory difficulties of the three PID controller parameters and generally, it fails for systems with time- varying, time-delayed, nonlinear, indistinct and complicated systems [3]. [5] discussed about Improved Particle Swarm Optimization. The fuzzy filter based on particle swarm optimization is used to remove the high density image impulse noise, which occur during the transmission, data acquisition and processing., Adaptive slope sigmoid function cascading neural network algorithm (ASCNNA) [6], Generalized Constructive training algorithm using ASAF Framework (ASAFCA) [7], New Constructive Algorithm (NCA) [8], An Adaptive Slope Basic Dynamic Node Creation Algorithm (ASBDNCA) [9] can be used. A Neural Network (NN) is a powerful data-modeling means to capture and represent complicated input/output associations. Even though PID controllers are prevalent by reason of cheaper, better performance in a broad range of operating conditions, ease of maintainability; there are restrictions in real-time situations. To overcome this, a type of structural improvement is introduced, that is variable structure control. Other methods include the combination of fuzzy theory, genetic algorithms, artificial neural networks and other intelligent control theories with the traditional PID control. Through these additions, the system achieved better robustness for the system parameters; the control is independent of an exact mathematical model and gave a vivid picture of the space-time tradeoff [10]. To solve hard problems in mathematics, neural networks are much capable because they have been confirmed to approximate any continuous function as perfectly asachievable. So, neural networks have received significant consideration in the process control domain.Because of the growing difficulty in the practical production process uncertainty, the conventional PID controller cannot meet the desired requirements. A theoretical foundation of the BP neural network is introduced and by using it the speed of the learning rate and shock reduction can be achieved. Since it is an adaptive network, continuously the network adjusts the three parameters of the PID controller [11].

II. METHODOLOGY

The problem analysis includes the general state space models, state space parameters for motor and tuning as a remedy for the performance improvement.

A. State space model

There are mainly threecases where the state space model can be obtained. If the desired parameters considering are known, the model can be achieved; When the parameters considering are unknown, then also the state space model can be determined and arma model with known and unknown parameter values. For calculating state space model with known parameters, the following steps can be used; specify the state transition coefficient matrix,identify the state disturbance loading coefficient matrix, find the measurement-sensitivity coefficient matrix and finally define the state space model using 'ssm' function. For unknown parameters, indicates matrices using NaN. In arma model, the following general equation is used.

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$$x_t = c+\phi_1 x_{t-1}+\phi_2 x_{t-2}+u_t+\theta_1 u_{t-1} \quad (1)$$

Only a small variation will come into the general equation while considering the known parameters and with no constant term.The matrices of a state-space model may vary depending on the plant structure.

B. State space parameters for motor

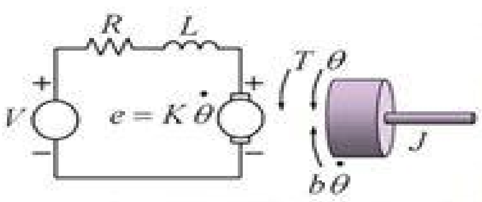

Fig. 3. Motor representation

The design requirements of a motor include settling time less than 40ms, overshoot less than 16% and no steady state error, even in the presence of a step disturbance input. In the state space analysis, the moment of inertia, damping ratio of the mechanical system, electromotive force constant, electric resistance, electric inductance are considered. Figure 3 represents the motor parameters.

$$\frac{d}{dt}\begin{bmatrix}\theta\\ \dot{\theta}\\ i\end{bmatrix} = \begin{bmatrix}0 & 1 & 0\\ 0 & -b/J & K/J\\ 0 & -K/L & -R/L\end{bmatrix}\begin{bmatrix}\theta\\ \dot{\theta}\\ i\end{bmatrix} + \begin{bmatrix}0\\ 0\\ 1/L\end{bmatrix} V \quad (2)$$

$$y = \begin{bmatrix}1 & 0 & 0\end{bmatrix}\begin{bmatrix}\theta\\ \dot{\theta}\\ i\end{bmatrix} \quad (3)$$

The above given equations are used for the state space analysis of the motor. The coefficient matrices obtained are as follows:

A = [0 1 0
0 -b/J K/J
0 -K/L -R/L]

B = [0 ; 0 ; 1/L]

C = [1 0 0]

D = [0]

After the generation of the coefficient matrices, the continuous time state space model is converted into state space form by using 'ss' function.

C. Ziegler-Nichols method

Ziegler-Nichols method, a heuristic method used for the purpose of PID tuning. This method is performed by increasing the proportional gain, Kp while keeping the integral and derivative gains (Ki and Kd) to zero. After an ultimate gain is reached with consistent oscillations is used to set the Proportional, Integral and Derivative gains.As per the requirement, the user is able to give the time constant, delay time, critical gain and its corresponding period values to the plant for achieving the proportional gain, the integral gain and the derivative gain.

III.WAFER STAGE SYSTEM

The wafer stage system consists of two modules: 1) the long stroke module which controls the long stroke motions with positioning accuracy in micrometer level and 2) the short stroke module which controls the short stroke motions with positioning accuracy in nanometer level. For positioning purpose, wafer stage actuator systems use linear motors as well as the voice coil motors. Linear motors are employed to control the long stoke motions of the long stroke module and voice coil motors are employed to control the short stroke motions of the short stroke module.

The motion control modules are controlled in six logical axes (Six degrees of freedom) that is in the up-down direction, left-right direction, forward-backward direction, roll axis, pitch axis and yaw axis. The schematic block diagram of the assemblies of the wafer stage with Artificial Neural network is shown in Figure 4. The linear time-invariant wafer stage plant P has output y, which may be corrupted by the unmeasured disturbances. The closed loop error,e is the difference between the reference command, rand the system output,y. This can be represented as follows:

$$e = r - y \quad (4)$$

Motor operation and its better performance have to be consideredfor theprecise positioning mechanism in the wafer stage system. So, more importance has to give in the actuator system in the wafer stage. Neural Network (NN) is applied in the actuator system for the control of precise motion task through a predefined reference trajectory.

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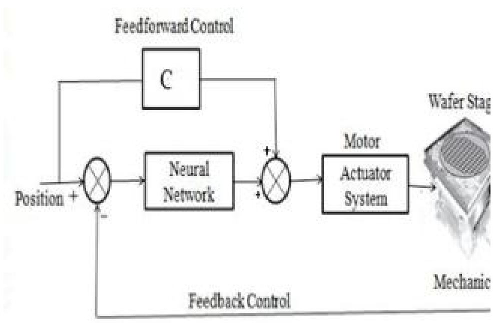

Fig. 4. Schematic block diagram of the wafer stage assemblies with Artificial Neural network.

IV.MODEL-BASED CONTROL

Advanced control theory includes both linear and nonlinear control theories. Zero-pole assignment, LQR design and robust control are incorporated in linear control design. Controller design methods include Lyapunov-based controller designs, back-stepping controller design, feedback linearization, etc. for non-linear systems. In model-based control design, the first step is modeling of the main plant in the industry or identifying the plant model, and then designing the controller is done based on the plant model. The modeling and identification of the plant arecompulsory crucial for the model-based control theory. Also, model-based approaches are a time-consuming as well as difficult process, data-driven controller tuning is an appealing approach in high-precision motion control.

V. DATA-DRIVEN CONTROL

Modeling processes have become more challenging with the development of information science and technology, practical processes in metallurgy, large machinery, electronics, chemical industries, etc.For this reason, traditional model-based control theory has turned into unrealistic for control issues.So, the formation and progress of data-driven control theory is urgent issues both in theory and application. The process in a data-driven control, its starting point and target are both data. Iterative Feedback Tuning (IFT) is such a data-driven control mechanism.

VI. ARTIFICIAL NEURAL NETWORK

A neural network is not just a complex system, it is a complex adaptive system, soit can change its internal structure based on the information flowing through it.Typically, this is achieved through the adjusting of weights. Each connection has a weight, a number that controls the signal between the two neurons. Back Propagation Algorithm (BPA) is used to train the values which are obtained from the demo setup. It consists of at-least three layers of units. They are an input layer, at-least one hidden layer and an output layer. In feed-forward fashion, these units is connected with input units connected to the hidden layer and it is then connected to the output units.

VII. RESULTS AND DISCUSSIONS

Through IFT, controller parameters can beeasily tuned.IFT is used to find the optimal set of controller parameters. The adaptation, which is made from the IFT approach is used for the computation of stability analysis, controller's fine tunings.Assigned the input data, r_1 and r_2 [2] are as follows:

$$[r_1^{<1>}(t) r_1^{<1>}(t)] = Q \sum_k a_k \, \text{Sin}(\omega_k + \Phi_k) \quad (5)$$

By using the inputs plant state space model is created, where u is the input vector or the control vector, y is the output vector, A is the system matrix. B is the input matrix, C is the output matrix and D is the Feedforward matrix.

$$\dot{x} = Ax + Bu \quad (6)$$
$$y = Cx + Du \quad (7)$$

An impulse, a step or a ramp signal can be used to analyze the time response. Here, the closed loop response is plotted for a step input. The closed loop response obtained is shown in Figure 5.

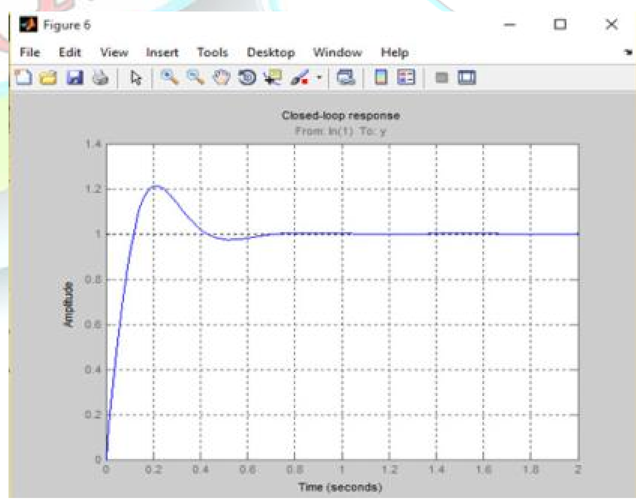

Fig. 5. The Closed loop response

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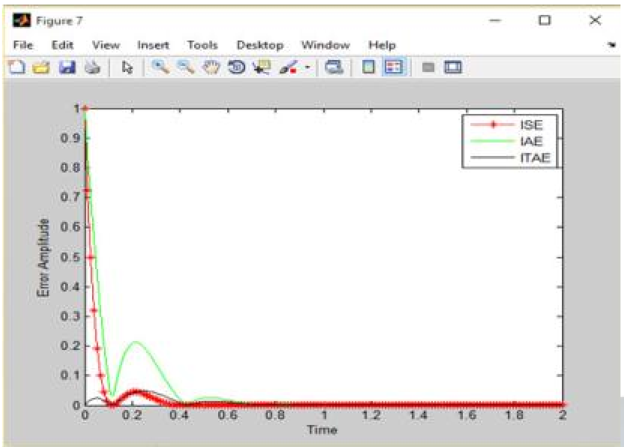

Fig.6. Error minimization

By comparing the Integral Square Error (ISE), Integral Absolute Error (IAE) and Integral Time Absolute Error (ITAE), it is found that the Integral Absolute Error technique minimizes the error effectively. An error minimization graph of ISE, IAE and ITAE are shown in the figure 6.

P (Horizontal Motor tilts)	T (Vertical Motor tilts)	X direction	Y direction
0	0	102	186
0	15	106	210
0	-15	104	153
15	0	145	211
-15	0	169	121
15	-15	33	212

Table 1. Horizontal values, P and vertical values T from the demo setup

X and Y are taken by averaging many input values from a demo setup which is used for taking the training values. Table 1 shows the results of training through Artificial Neural Networks.

VIII. CONCLUSION

A Back Propagation Algorithm (BPA) has been developed with three units, including the input section, hidden layer part and output section. Artificial Neural Network (ANN) is effectively applied to the system, to train the data values which are obtained from the demo setup. So, by using this approach in the wafer stage system, precise motion task can be performed through a predefined reference trajectory. The error which is formed during the positioning can be minimized with the Integral Time Absolute Error minimization technique.

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