

DIFFERENTIAL ACTUATION TECHNIQUE FOR SUB-NANOMETER ACCURACY

Field of the Present Invention

The invention is a differential actuation technique that employs multiple counteracting actuators to achieve highly accurate position and motion control in even sub nanometer expanse exploiting the resultant motion/position of the actuators for translational and rotational motions to achieve its objectives.

Objects of the Present Invention

The main object of the present invention is to reduce or eliminate inherent and extraneous positional error and nonlinearity of actuation in positioning and motion control.

Another main object of the present invention is to extend the performance of positioning and motion control in terms of bandwidth/speed, accuracy, range and resolution.

Yet another object of the present invention is to increase the noise immunity

Brief description of the Accompanying Drawings

Figure 1 shows use of two counteracting actuators for each translational or rotational axis.

Figure 2 shows rapid actuation with reduced latency by (Fig 2a) expanding actuator A1 and contracting actuator A2 and vice versa or by (Fig 2b) expanding or contracting both actuators.

Figure 3 shows that rise time in a capacitor is a function of applied current

Detailed description of the present Invention

The differential actuation technique is applicable and well suited for various applications in macro world to sub-nano world as well, of translational and rotational motion/ positioning using various kinds of actuators. It is most suited for performance enhancement in Nanopositioning and Nanomanipulation.

Motion/Position control using two actuators

Here two counteracting actuators are used for each translational or rotational axis as shown in the figure 1(a) and 1(b) respectively. The objectives can be achieved using this technique as follows.

Let us consider two counteracting actuators with individual positions/displacements d_1 and d_2 having errors e_1 and e_2 respectively in any instant of time. With proper coupling mechanism of actuators with the subject to be actuated and mounts, the position d of the subject is the resultant of the positions/displacement of the two actuators.

$$d = d_1 \sim d_2 + e_1 \sim e_2$$
$$\Rightarrow d = d_r + e_r$$

Here the resultant position of the subject contains error equal to the difference of the individual error of the two actuators. So for the requisite resultant, the two actuators can be moved to achieve accurate position/displacement/motion with much reduced error. The performance in this technique can be further enhanced by using actuators with similar characteristic so that the error in the actuations cancels out. In case, where the error is a function of the operating parameters, either a model of the system can be used to pre calculate the error in the actuators and compensating excitations in the opposite actuator can be applied so that the error cancels out, or by continuous monitoring of the position/motion error of the subject and applying the corresponding correction of position/motion to the counteracting actuators, or using both the techniques. The technique has a lot of performance enhancement capability and advantages in Nanopositioning, Nanomanipulation and Nano motion control.

The nonlinearity and hysteretic error in actuation present in many types of actuators can be reduced by counter feeding the nonlinearity/hysteretic error estimates obtained through either proper modeling of the actuators and/or continuous monitoring of its operation.

The noise in precision motion/position control is one of the downbeats in its accuracy and performance. The present invention effectively reduces the noise issue as the error due to noise in both actuators get effectively cancel out or extraneous noise in one

actuator can be feed to the other for cancellation and noise impend minimum effect in accuracy of actuation.

The differential actuation technique can be particularly useful in stabilizing subject against thermal drifts in many types of actuations using actuators with similar characteristics. The technique can work as a dynamic thermal self compensator and reduce error due to thermal dependence in certain actuators and motion guides.

In applications where solid state actuators are in wide use, system stiffness is one of the key parameters for bandwidth constraints. The present technique effectively increases the system stiffness and enhances the bandwidth manifolds.

The technique also enables to increase range of actuation two fold in each axis, the schematic 1 is self explanatory.

The technique is further applicable in magneto, electro, opto or thermo mechanical/electrical actuators with hysteretic or stick slip errors. The slip stick error can be minimized if both the actuators are excited simultaneously.

Nanopositioning and Nanomanipulation

The thrust of ultra precision devices led to development of many new techniques. Nanopositioning and nanomanipulation systems employ solid state smart actuators mounted over precision motion guides to achieve accurate nanometer resolution position and motion control. A typical Nanopositioning system consists of a piezo actuator mounted over a flexure guide stage driven by an open loop/closed loop piezo controller. There exist certain shortcomings that constraints ultra high accuracy related to actuator, flexure and drive electronics. The invention addresses these issues to a large extend to enable sub nanometer/ picometer accuracy. Possible schemes for Nanopositioning application is as shown in figure 2.

The motion guide consists of flexure stage with platforms, 1, 2, and 3, with driving actuators A1 and A2 and subject to be actuated sits on platform 0. Here the position/motion of the subject can be controlled by both actuators A1 and A2. Actuator

A1 moves platform 1 whereas actuator A2 moves platform 0, both together counter actuating the subject, forms a differential mechanism in which the motion/position of the subject is resultant of the motion/position of the two actuators.

The bandwidth limitation with piezo actuators is basically owing to its capacitive behavior and the displacement is a function of equivalent charge accumulated. Since the raise and decay in a capacitor can be given by an exponential law, the actuator takes a finite time to move to commanded position and come back to its original position and this latency in actuation can be attributed to its equivalent capacitance. The differential actuation technique provides a physical solution to this electrical problem. The rise time in a capacitor is a function of applied current; more is the current more quickly it will reach the desired level of charge. Similarly a large negative current depletes the charge quickly. This technique achieves high bandwidth and hysteretic nonlinearity reduction with unipolar supply by forced reverse compensating motion from the complimentary actuator, using dynamic stiffness control technique (Figure 3).

A rapid actuation can be achieved with reduced latency by (Fig 2a) expanding actuator A1 and contracting actuator A2 and vice versa or by (Fig 2b) expanding or contracting both actuators.

The bandwidth largely depends upon the settling time of the system, which in turn depend upon physical parameters of the system and control system parameters. The present technique reduces the settling time with nanometer accuracy by compensating any overshoot in actuation of actuator A1 by counter actuation of actuator A2 and vice versa.

The stiffness of the system also contributes largely on the bandwidth of the system. Each flexure joint works as a spring. The system of flexure and actuator works with the counter acting forces of the expanding actuator and the restoring force of the spring. Thus a stiffer the system has a larger the bandwidth. The differential actuation technique scheme increases the stiffness of the system and hence contributes to enhanced bandwidth.

The accuracy of a nanopositioning system is largely affected by noise and drift in the system. The sources of noise are primarily electronic and thermal and induced from the control and power supply. The sources of drift are thermal and time. These factors are common to both actuators to a large extent and thus get canceled out. Any extraneous factors including noise and drift, affecting the accuracy can also be made to cancel out by counter feeding in the actuators.

One of the major shortcomings of nanopositioning with solid state actuators is the inherent hysteretic nonlinearity. The hysteresis is the phenomenon in which equal level of excitations produces different level of actuations for increasing and decreasing excitations. The compensation for these kinds of errors is inaccurate due to inaccuracy in predicting the required level of excitation for same actuation. This severely affects the repeatability of the system. The hysteretic nonlinearity in one actuator can be reduced to below concerned level by applying compensating excitation to the other actuator either by dynamic monitoring of the error or precalculating the error through a model without considerable overshoot or undershoot and much reduced settling time.

Rate dependent nonlinearities in certain actuators can also be compensated using this technique.

Claims

1. A method to reduce or eliminate inherent and extraneous positional error and nonlinearity of actuation in positioning and motion control by way of differential actuation technique employing multiple counteracting actuators to achieve highly accurate position and motion control in even sub nanometer expanse exploiting the resultant motion/position of the actuators for translational and rotational motions.
2. A method to extend the performance of positioning and motion control in terms of bandwidth/speed, accuracy, range and resolution by way of differential actuation technique.
3. A method to increase the noise immunity by way of differential actuation technique.