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ACTUATOR CONTROLLER

FIELD OF THE INVENTION

5 This invention relates to actuator controllers. Particularly preferred embodiments of the invention relate to actuator controllers for data storage devices, such as hard disk drives (HDDs) for example.

BACKGROUND OF THE INVENTION

10 Fig. 1 is an illustrative representation of a typical hard disc drive (HDD) 10 shown in an exploded form. As shown, the drive comprises a read/write (R/W) head 20 for reading data from or writing data to a platter 30 (made, for example, of aluminium, or aluminium alloy, or glass) that has a data-recording surface (such as a thin film magnetic data-recording surface) formed thereon. The platter 30 is mounted on a spindle 40 and is rotatable by a spindle motor (not shown).

15 The R/W head is carried on a slider 50 that is connected to one end of an actuator arm 60, and the other end of the arm is rotatably mounted on a pivot pin 70. A drive mechanism (indicated generally by reference numeral 80) provides a torque for rotating the actuator about its pivot to move the head radially back and forth across the surface of the platter.

20 The particular drive shown in Fig. 1 includes a number of data storage media, or platters as they are more commonly known, arranged one on top of the other in a stack. For ease of explanation, the following description will refer to a HDD with a single platter, but it should be noted that the scope of the invention is not limited to such an arrangement.

25 Data is stored on the platter in individual data clusters that are arranged in generally concentric tracks on the disc surface. In most modern HDDs the data clusters are interspersed with servo codes which are recorded onto the disc at the time of its manufacture, and in some older drives a separate platter is reserved exclusively for servo codes. The servo codes are
30 read by the R/W head as it travels across the surface of the disk, and are interpreted to provide a control mechanism (indicated generally as printed

circuit board (PCB) 90, and associated with the aforementioned drive mechanism) with an indication of the position of the head over the surface of the disk.

5 In most computer systems the HDD is the main data storage device, and as such the performance of the HDD tends to have a significant impact upon the performance of the computer system as a whole. As a consequence, it is desirable to design the HDD so that it operates as quickly as possible. To this end it is desirable to provide a system which is able to track quickly to a given sector or sectors on a disk (a so called "seek" operation), as well as
10 being able to accurately follow a given concentric track (a so called "track" operation). Any given read or write operation typically requires the HDD to perform both a seek operation (to move the R/W head to the position on the disk where data is stored) and a track operation (to read out the contents of one or more clusters where data is stored).

15 A problem facing the designer of a HDD is that the drive characteristics for the aforementioned "track" and "seek" operations are markedly different to one another. For example, in a "seek" operation the head needs to be moved a relatively large distance radially over the surface of the drive as quickly as possible in order to reduce the time required to get the
20 heads into the correct position for data reading/writing. In a track operation, however, the head needs to be capable of following a given track on the data storage medium and to this end the drive mechanism 90 must be capable of moving the head slowly and in relatively small increments all the while keeping the head in accurate alignment with the track.

25 A further problem results from the fact that a given read or write operation will typically require both a seek operation and a track operation, and thus the control mechanism 90 must be capable of controlling the drive mechanism 80 to move quickly from one mode to the other. In other words - using parlance more commonplace in the art - the "settling time" (i.e. the time
30 taken for the heads to settle from a seek operation into a track operation) should be as small as possible.

In summary, therefore, to provide a HDD with an acceptable level of performance, the drive mechanism 80 and associated control mechanism 90 must be capable of moving the heads in a first mode where speed of movement is paramount and accuracy is less important, in a second mode
5 where speed is less important and accuracy is paramount, and be capable of switching quickly from one mode to the other, and visa versa.

In most modern HDDs, the drive mechanism 80 comprises a voice coil actuator that is operable to position the head over the surface of the data storage media. The voice coil actuator and associated control mechanism are
10 one example of what is commonly called a servo system which – as is well known in the art - is a type of closed-loop feedback system.

For acceptable performance the servo system should be capable of accurately positioning the head even in the presence of anomalies or changes in the disk drive mechanism (such as changes induced by temperature
15 fluctuations, or anomalies introduced by external vibrations). These changes or anomalies can result from problems with the actuator, the spindle or the disk, from deviations from perfect circularity in the tracks, and from variations of the read back signal (the so-called position error signal (PES)) used for feedback control.

20 Typically, most previously proposed control systems have employed linear controllers for tracking operations and non-linear controllers for seek operations.

For example, it has previously been proposed to provide a non-linear control that provides a fast move without causing excessive excitation of the
25 actuator flexible mode (i.e. the resonant mode of the actuator). Saturated control current (maximum or minimum value) or non-saturated control current is typically employed, in dependence upon the length of the move and how fast a move is desired. One example of a such a previously proposed control is the so-called bang-bang control described in the article by H.T Ho
30 entitled “Fast servo bang-bang seek control” (see Pages 4522-4527 of IEEE Transactions on Magnetics, Volume: 33 Issue: 6, Nov. 1997). Another

example of a smoothed version of bang-bang control is described in United States Patent No. 4,783,705 (to Moon et al).

Another previously proposed example of a linear controller includes both an initial value compensator (IVC) and a track following controller (see the article by T. Yamaguchi, et al. entitled "A mode-switching control for motion control and its application to disk drives: design of optimal mode-switching conditions," (Pages 202-209 of Mechatronics, IEEE/ASME Transactions on, Volume: 3, no. 3, Sept. 1998). The IVC, typically designed using linear control theory, helps to reduce the settling time by compensating for the non-zero initial states induced by a seek operation.

Another previously proposed track controller comprises a proportional-integral-differential (PID) controller in combination with a compensator for the actuator flexible mode. Many higher order linear controllers resemble the PID controller in terms of frequency response behavior. In general terms, it is desirable that the track controller has the following performance criteria: (1) a zero, or near zero, steady state error; (2) a robust reaction to friction; (3) a relatively poor response to measurement noise; (4) a robust reaction to disturbances; and (5) a fast rise with little - or preferably no - overshoot.

Criteria (1) to (3) can be accomplished by providing a high gain linear integrator in the control system together with proper shaping of the servo loop gain. However, such an approach tends to make it harder to achieve the fourth and fifth performance criteria which are high-speed dynamic response characteristics. Another problem is that meeting the third criteria tends to require a relatively moderate servo loop gain so that the servo system will have relatively less response to the noise.

As the design criteria can tend to conflict with one another it is not uncommon for misalignment, or delayed alignment, of the read/write heads with respect to the tracks to occur, and this causes an increase in read/write errors and a slowdown in read or write operations.

Non-linear controllers appear to offer a feasible alternative to linear controllers in that there are often more free parameters available for tuning, and hence there is often a greater potential to provide a servo control system with better performance.

5 Non-linear controllers, such as non-linear finite impulse response (FIR) filters, have previously been proposed for use in a disc drive.

United States Patent No. 5,721,477 (to Sepehri et al) discloses a non-linear proportional integral controller that employs a position error integral signal which includes a velocity factor that is based on a derivative of the position error and a non-linear function. This controller is also operable to
10 reduce overshoot by further modifying the position error signal in dependence upon whether the velocity and acceleration of position are in the same direction. Stiction at deadband areas is avoided by determining a stick induced velocity error signal and modifying the control signal when required.

15 A problem with this system stems from the fact that as the controller depends on velocity, it is only applicable to systems whose velocity is available or can be estimated accurately. During the tracking mode in a HDD, it is difficult to estimate the actuator velocity accurately and thus this system is not practically feasible.

20 There remains therefore a need for a simple yet effective controller for improving the operation of a servo system given the mechanical limitations of the actuator. The present invention provides a means for addressing these and other problems, and offers other advantages and/or alternatives to the prior art.

25 SUMMARY OF THE INVENTION

In accordance with an embodiment of the invention, there is provided a controller having the features of Claim 1. In general terms, a preferred embodiment of the invention uses non-linear functions to combine two or more types of linear controllers to provide better transient and steady state
30 performance than is attainable by using individual linear controllers on their own.

In a particularly preferred embodiment, the non-linear section includes n static functions (where $n \geq 2$) which can be implemented as look-up tables (LUTs) with the control error as the inputs, and the outputs are connected to n usual linear controllers of different parameters. The LUTs offer different
5 amplifying factors to errors of different amplitudes. Between the points in the LUT, linear interpolation is used. At least two LUTs, one to respond to small error signals, and the other to respond to larger error signals, are employed. The linear controller that reacts to small error signals can be a normal track following controller where as the linear controller for large error signals is
10 designed specially for large errors.

Additionally, the proposed non-linear controller can be used together with the actuator model to form a non-linear reference trajectory generator. In this case a “soft” reference change instead of the abrupt step change is used for the closed-loop system, and a non-linear controller can be arranged to
15 follow this soft reference change. Because the reference signal is smoother and contains less high frequency harmonics, the actuator resonance modes are less likely to be excited. Furthermore, the soft reference signal can help to reduce the overshoot of the closed-loop feedback control system without changing the feedback controller.

20 The present invention offers a non-linear track following controller that can be easily be implemented in a HDD that is designed to have a traditional linear track following controller. In addition, it avoids the difficulties encountered by conventional non-linear control designs that require much more computational power due to various non-linear operations
25 involved. Furthermore, in comparison with neural networks and other non-linear controllers, tuning of the controller only needs the adjustment of the relative values of the two LUTs.

These and various other features as well as advantages that characterize the present invention will be apparent upon reading of the
30 following detailed description and review of the associated drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of a previously proposed HDD;

FIG. 1a is a block diagram illustrating components of the control system of the HDD of FIG. 1;

5 FIG. 2 is a control system block diagram representing the HDD servo system of FIG 1;

FIG. 3 is a schematic view of a non-linear controller according to a preferred embodiment of the invention;

10 FIG. 4 shows the frequency responses of a PD and a PID type controller that could be used in the control system depicted in FIG. 2 and FIG. 3;

FIG. 5 illustrates the frequency responses of the PD and PID controller shown in FIG. 4 in cascade with an actuator model. These curves are known as the compensated open-loop frequency responses, or open-loop frequency responses for short;

FIG. 6 and FIG. 7 illustrate the relationships between input and output signals for the look-up tables shown in FIG. 3;

FIG. 8 is a block diagram of another embodiment where a non-linear function is implemented in a digital to analogue converter (DAC);

20 FIG. 9 is a block diagram of another embodiment where two non-linear functions are implemented in a single DAC;

FIG. 10 is part of a block diagram of a normal known linear DAC;

FIG. 11 is a block diagram of the non-linear DAC used in FIG. 8;

25 FIG. 12 is a block diagram of the non-linear DAC used in FIG 9, with the outputs summed using an operational amplifier;

FIG. 13 is a schematic representation of a reference signal generator employing the non-linear controller shown in FIG. 3;

30 FIG. 14 is a schematic representation of a closed loop servo system that employs the reference signal generator of FIG. 13, and either of the non-linear feedback control systems shown in FIG. 3 or FIG. 8; and

FIG. 15 is a schematic representation of a computer system.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 is an exploded perspective view of a previously proposed HDD 10. As shown, the disc drive includes a number of rotating disks 30 which are mounted on a spindle 40, and which can be rotated by a spindle motor (not visible).

The R/W head 20 is mounted on one end of an actuator arm 60, that can be rotated about a pivot point 70 by means of a drive mechanism 80 (typically a voice coil motor (VCM)) under control of a control mechanism comprising components on a PCB 90.

FIG. 1a illustrates, as a block diagram, the functional components of the control mechanism 90. As mentioned above, as the R/W head moves over the surface of the platter(s) it picks up a signal which is amplified and filtered, and then passed to a position error signal (PES) demodulating circuit 100 which detects the servo codes and outputs a PES that is representative of the difference between the current location of the head, and the target location of the head. The R/W head is usually a magneto-resistive head or a giant magneto-resistive head which outputs a non-linear signal, and as a consequence it is normal for the PES demodulator 100 or controller 120 to include components that provide a linearised PES.

The linearised PES signal is passed via an analogue to digital converter 110 to a servo control circuit 120 which calculates, in a digital format, the control signal required to move the head from its current position to its target position. This control signal is converted back into an analogue drive signal by a digital to analogue converter 130 and output to a VCM driving circuit 140.

The servo control circuit 120 is typically implemented in a digital signal processor (DSP), or a micro-controller, or in the form of digital infinite impulse response (IIR) filter. The control circuit 120 embodies various correction functions to deal with disturbances such as windage, disk fluttering, amplifier noise, external vibration, and measurement noise. Normally, the error rejection transfer function (or sensitivity transfer function)

and the complementary sensitivity transfer function of the control circuit 120 are carefully selected by the servo designer to provide desired disturbance rejection and noise attenuation capabilities.

FIG 2 is a control system block diagram corresponding to the servo system shown in FIG 1a. Here the dynamics of the actuator assembly - including the VCM, the actuator arm, suspension for the arm, and a slider on which the R/W head is carried - are represented as an actuator model 150 which can be represented as transfer function or state space model.

For simplicity, the transfer function of the VCM drive circuit 140 is also represented as part of 150. The VCM driving current saturation due to limited voltage supply to the driver circuit is approximated as a saturation section 160. The various disturbances (including, for example, repeatable runout (RRO) and non-repeatable runout (NRRO)) in the servo loop are lumped together as a time series 170. Noise present in the servo loop is lumped together as noise data, and is shown as another time series 180. The digital servo control circuit 120 has two parts, a filter 190 which deals with the flexible modes of the actuator and a basic feedback control section 200.

Generally speaking, the basic feedback control section 200 provides some sort of proportional-integral-differential (PID) action whereas the filter is typically a kind of notch filter that functions to suppress the actuator flexible mode (i.e. the resonant mode of the actuator).

The servo system is fed by a reference drive command 205, and this will typically be a step signal with an amplitude that varies in dependence on the numbers of tracks the R/W head is to be moved. As an alternative, the drive command could be a smoothed version of a step signal. In either event it is usual for the drive command to be pre-calculated and stored as a series of values in a look-up table (LUT).

FIG 3 illustrates one embodiment of a controller in accordance with the invention. In general terms, the controller of this embodiment comprises two normal linear controllers each in cascade with a non-linear look-up table, one controller/LUT pair being provided for operations with larger error signal

values, and the other controller/LUT pair being provided for track following operations with smaller error signal values.

In this embodiment the second controller/LUT pair comprises a normal track following controller 210 in cascade with a non-linear LUT 220. This second controller/LUT pair works in parallel with a first controller/LUT pair that comprises a controller 230, which is designed with fast settling performance in mind, in cascade with another non-linear LUT 240. The LUTs 220 and 240 are designed in an *ad hoc* way, with values being chosen to give a desired performance. One example is given later.

An error scaling unit 250, which is a pure gain K , and an error de-scaling unit 260, having a gain of $1/K$ are provided to fine tune the control effects.

An advantage of this arrangement is that the LUTs 220,240 can also be used to take care of the aforementioned PES non-linearity calibration. That is, the PES non-linearity calibration function and the LUTs can be merged to form newer LUTs. As an example, the controller 210 could simply be a commonly available proportional-integral-differential controller (PID), and the controller 230 could simply be a commonly available proportional-differential (PD) controller.

FIG. 4 illustrates the frequency responses of the controllers. These controllers, when connected with the actuator model, would yield the compensated open-loop frequency response as shown in FIG 5. In the preferred embodiment, the open loop 0-dB crossover frequency for controller 210 and 230 are intended to be approximately the same so that there is no extra requirement on the actuator performance.

Also as an example, the characteristics of LUT1 and LUT2 are shown in FIG 6 and FIG 7. In FIG 6, the small signal gain is intentionally reduced so that controller 230 is only effective for large error signals. In FIG 7, the error signal amplitude is clipped so that the compensator 210 is effective for small amplitude error signals. When the error signal amplitude is large, the effect of the controller 210 will be reduced because of the capping effect of 220. Here

the LUTs can be implemented in the firmware of the digital signal processor, (DSP) or the micro-controller. Alternatively, hardware implementation is also possible.

The key point of this embodiment is the use of the non-linear LUTs to determine which linear controller is to have a greater influence on the overall response to an input signal. As such, the LUTs in FIGs 6 and 7 were tuned by trial and error in such a way that when the error signal is large, the PD controller 230 will exert a greater influence on the overall output performance. Conversely, when the error is small, the PID controller 210 will have a greater say in the overall output response. As can be observed from FIGs 6 and 7, LUT 240 (FIG 6) will cause the linear controller 230 connected to it to be less responsive to error signals smaller than ± 1 , whilst LUT 220 (FIG 7) will result in a less responsive linear controller for error signals larger than ± 1 . In doing so, the twin control objectives of low frequency control gain and steady state tracking accuracy can be attained.

Comparing the proposed non-linear control system, which we call nonlinear PID or NPID, as represented by FIG 3, with the pure PD controller and PID controller, the following results can be obtained for an HDD servo system:

Case 1:

	PD	PID	NPID
Crossover frequency (rad/s)	20212	19948	-
Gain Margin (dB)	10.2	10.1	-
Phase Margin (°)	59	52	-
PES 3σ , in μ in	2.82	2.88	-
PES 3σ , in μ in, K=0.8	-	-	2.5
PES 3σ , in μ in, K=1	-	-	2.49
PES 3σ , in μ in, K=1.2			2.48
PES 3σ , in μ in, K=1.4			2.49

Case 2:

	PD	PID	NPID
Crossover frequency (rad/s)	21004	20679	-
Gain Margin (dB)	7.9	7.8	-
Phase Margin (°)	56.7	49.5	-
PES 3σ , in μ in	2.51	2.43	-
PES 3σ , in μ in, K=.8	-	-	2.34
PES 3σ , in μ in, K=1	-	-	2.33
PES 3σ , in μ in, K=1.4	-	-	2.30

As can be seen from these tables, the tracking performance measured by PES 3σ (n.b. smaller is better) can be improved by means of this embodiment.

FIG 8 illustrates another embodiment of the invention. In this embodiment, the system comprises three controllers 280, 290 and 300 which can be implemented in digital signal processors, or in the form of hardware digital IIR filters using bit-arithmetic.

In this embodiment, the non-linear LUTs 220, 240 shown in Figure 3 have been merged with the digital to analogue converter 270 (see FIG. 3) to form two non-linear DACs 310, 320. The outputs of the non-linear DACs 310 and 320 are added together by an operational amplifier 330. In a modification of this embodiment, the non-linear DACs 310 and 320 (as shown in detail in FIG. 11) and the adder (operational amplifier 330) could be integrated in one module as a stand alone integrated circuit (IC), or part of an IC that combines more of the functions of the system.

As a further alternative, the DACs 310, 320 could be configured as shown in FIG 12 with more than one resistor ladder, the outputs of which are added to one another. FIG. 12 shows one example of such an arrangement where the non-linear DAC has two resistor ladders.

Referring now to FIG. 10, a normal known DAC employs a latch 340 to receive and retain data, and a resistor network 350 that generates the necessary current to amplify an input signal. As is well known in the art, the output voltage, V_o , of the circuit is proportional to an m bit input digital signal, and may be written as follows:

$$V_o = (b_1 2^{-1} + b_2 2^{-2} + \dots + b_m 2^{-m}) V_{ref}$$

where b_i , $i = 1, 2, \dots, m$ equals either 0 or 1; b_1 being the most significant bit (MSB) and b_m being the least significant bit (LSB) for an m -bit input signal.

In contrast to this known arrangement, a non-linear DAC incorporates a different set of weighting resistors. Referring now to FIG 11, the non-linear DAC 360 uses different resistor values. For example, if $R_1 = R_2 = 4R$, and $R_3 = 2R$, then the LSB weights will be smaller. Similarly, if $R_1 = R_2 = 1.5R$, and $R_3 = 0.5R$, then the LSB weights will be larger.

FIG 12 is a block diagram of a non-linear DAC with two non-linear functions. When two non-linear functions are combined into one non-linear DAC (as opposed to providing two separate non-linear DACs), the outputs need not be summed by an operational amplifier (as is required in the embodiment shown in FIG 8). This is advantageous as it allows for the number of components in the system to be reduced, and hence for the system to be manufactured more cheaply. FIG 9 is a schematic representation in block form of a control system that employs a single DAC with two non-linear functions.

In yet another embodiment (shown in FIGs. 13 and 14), a non-linear controller is used to generate a position reference trajectory for the closed-loop servo to follow. Referring to FIG. 13, the non-linear controller (represented by block 370) generates a correction signal, which is in turn limited by a control limiter 380. The range of the limiter can be different from the actual closed-loop control allows (to enable additional different profiles to be generated). The correction signal is amplified and integrated by a digital integrator 390. The output of the integrator (the “integrator value”) represents the velocity trajectory, and thus it will saturate if its value exceeds the

maximum allowable velocity. The amplification gains k_v and k_y are determined by the gain of the actuator model (typically in the form of

$\frac{b_1 s' + b_2 s'^{-1} + \dots + b_l}{s'' + b_2 s''^{-1} + \dots + b_n}$) when it is approximated by a double integrator model

$$\frac{k}{s^2}.$$

5 In this embodiment, all the non-linear functions are implemented in software although some non-linear sections could instead be implemented as hardware. For example, the non-linear correction function could comprise the LUT-linear control combination described previously. Alternatively, the non-linear correction function could be provided by any other type of the non-linear controller.

10 The velocity signal output by the integrator is multiplied by multiplier 400 with a signal of either one or zero output by a relational operator 410, and is further amplified and integrated by a discrete-time integrator 420 before being output as a position reference signal 430.

15 The position reference signal 430 is fed back to an adder 440 which outputs the difference between the position reference signal and an actual head position signal 450 input thereto. The output of the adder 440 is fed to block 460, and block 460 generates the absolute value of the difference.

20 The relational operator 410 compares the absolute value of the difference with a predetermined value output by block 470, and outputs a “zero” if the difference is larger than the predetermined value, and a “one” if the difference is smaller than or equals to the predetermined value.

25 In other words, when the absolute value of the difference between the position reference signal and the actual position of the R/W head is bigger than the pre-determined value, the relational operator 410 will output a zero which will null the input to the integrator 420 that outputs the reference trajectory, and hence output of the position reference signal will freeze.

FIG 14 illustrates a servo system that combines the trajectory generator shown in FIG 13 with the control system shown in FIG 8 to form a

servo system with a soft reference signal generator. Due to the use of the above described reference signal generator, the reference signal is smoother than the step change previously used and as a consequence it is less likely that the actuator resonant mode will be excited. As an alternative to the arrangement shown in FIG 14, the trajectory generator of FIG 13 could of course be combined with the control system of FIG 3 or FIG 9.

FIG. 15 is a schematic representation of an illustrative computing resource 480 in which the invention finds utility. The resource 480 comprises a central processing unit (CPU), a memory 490, a hard disc drive 500, a visual display unit (VDU) 510, a keyboard 520, and – in this preferred embodiment - a communications port 530, coupled to a communications channel 540 (such as an ISDN link). These elements are interconnected via a conventional bus structure (not shown). The hard disc drive 500 may incorporate any of the controllers herein described.

It is to be understood that even though numerous characteristics and advantages of various embodiments of the present method have been set forth in the foregoing description, together with details of the configuration and function of various embodiments of the method, this disclosure is illustrative only, and changes may be made in detail, especially in matters of structure, arrangement, and parameters of LUTs, and the number of bits and different combination of the resistor values in the non-linear DAC, and number of linear compensators and the number of LUTs, without departing from the scope and spirit of the invention.

For example, depending on the servo bandwidth and access speed requirements, it is possible that the read/write head may include a secondary stage actuator on the end of the actuator arm. In such an arrangement the VCM would provide for coarse movement of the head, and the secondary stage actuator would provide for fine positioning of the head. In such an arrangement the controller(s) of the various embodiments described above will have to calculate both the necessary control signals for the VCM and the secondary stage actuator.

WHAT IS CLAIMED IS:

1. An actuator controller for a disc drive, the actuator controller comprising:
 - 5 a plurality of control devices, each control device being configured to implement a predetermined transfer function and being responsive to an input signal to modify said input signal in accordance with said transfer function to generate an output signal;
 - weighting logic operable to weight said control devices so that at least
10 one of said control devices has a greater effect on an input signal than at least one other of said control devices; and
 - a summer for summing output signals from said plurality of control devices to generate a signal for use in the generation of a drive signal.
- 15 2. An actuator controller according to Claim 1, wherein each of said control devices are configured to implement a linear transfer function.
3. An actuator controller according to Claim 1, wherein said weighting
20 logic comprises a plurality of components that are each configured to implement a non-linear transfer function.
4. An actuator controller according to Claim 3, wherein each weighting
logic component is coupled to a control device and said non-linear transfer
functions are arranged to be complementary so that for a given input signal
25 value of a range of input signal values a said weighting logic component and coupled control device has a greater effect on said input signal than at least one other of said weighting logic components and coupled control devices.
5. An actuator controller according to Claim 4, wherein said non-linear
30 transfer functions are implemented as look-up tables.

6. An actuator controller according to Claim 5, wherein said look-up tables are implemented in a digital signal processor.
7. An actuator controller according to Claim 5, wherein said look-up
5 tables are implemented in a micro-controller.
8. An actuator controller according to Claim 5, wherein said look-up tables are implemented as part of a digital to analogue converter.
9. An actuator controller according to Claim 5, wherein said look-up
10 tables are configured to linearize a position error signal.
10. An actuator according to Claim 1, wherein said transfer functions are adapted to compensate sources of error and/or noise in said disc drive.
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11. An actuator controller as claimed in Claim 1, wherein said summer comprises an operational amplifier.
12. An actuator controller for a disc drive, the actuator controller
20 comprising:
first and second control devices, each control device being configured to implement a predetermined transfer function and being responsive to an input signal to modify said input signal in accordance with said transfer function to generate an output signal;
25 first and second weighting logic components coupled to said first and second control devices respectively, said logic components being operable to weight said control devices so that one of said first and second control devices has a greater effect on an input signal than one other of said first and second control devices; and
30 an adder for summing output signals from said first and second control devices to generate a signal for use in the generation of a drive signal.

- 13 An actuator controller according to Claim 12, wherein said first and
second control devices are each configured to implement a linear transfer
function.
- 5
14. An actuator controller according to Claim 13, wherein said first and
second control devices comprise a proportional-differential controller, and a
proportional-integral-differential controller.
- 10 15. An actuator controller according to Claim 12, wherein said first and
second weighting logic components are each configured to implement non-
linear transfer functions.
- 15 16. An actuator controller according to Claim 12, wherein said first and
second control devices comprise look-up tables.
17. An actuator controller according to Claim 16, wherein said look-up
tables are implemented in a digital signal processor.
- 20 18. An actuator controller according to Claim 16, wherein said look-up
tables are implemented in a micro-controller.
19. An actuator controller according to Claim 16, wherein said look-up
tables are implemented as part of a digital to analogue converter.
- 25
20. An actuator controller according to Claim 16, wherein said look-up
tables are configured to linearize a position error signal.
21. An actuator controller comprising:
- 30 first and second look-up tables configured to implement different but
complementary non-linear transfer functions, each of said look-up tables

being operable in response to an input signal to modify said input signal in accordance with said transfer function to generate an output signal;

first and second control devices coupled to said first and second look-up tables respectively, said first and second control devices being configured to implement a linear transfer function and being responsive to signals input from said first and second look-up tables respectively to modify said signals in accordance with said transfer function to generate an output signal; and

means for summing said first and second control device output signals to generate a signal for use in the generation of a drive signal.

22. An actuator controller according to Claim 21, wherein said first control device is configured to be appropriate for use in seek operations, and said second control device is configured to be appropriate for use in tracking operations.

23. A digital to analogue converter comprising one or more resistor ladders each comprised of a plurality of resistors, wherein at least some of said resistors have a different resistance to other resistors in said ladder to establish a non-linear relationship between digital signals input to said converter and analogue signals output from said converter.

24. A digital to analogue converter according to Claim 23, comprising first and second resistor ladders each comprised of a plurality of resistors, wherein said resistors of said first ladder have resistances that provide a first non-linear relationship between digital signals input to said converter and analogue signals output from said converter, and wherein said resistors of said second ladder have resistances that provide a second non-linear relationship between digital signals input to said converter and analogue signals output from said converter.

25. A digital to analogue converter according to Claim 24, wherein said first and second relationships are different.

26. A hard disc drive comprising:

- 5 a platter bearing at least one data storage layer;
 an actuator comprising an arm having a first end and a second end;
 a head assembly mounted on said first end of said arm, said head assembly comprising one or more read and/or write heads operable to write data to and/or read data from said data storage layer;
10 a motor for driving said second end of said arm to rotate said actuator about a pivot point; and
 an actuator controller as claimed in Claim 1, said actuator controller being operable to generate signals for use in the generation of drive signal for operating said motor.

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27. A computer system comprising a central processing unit, a display, and an input device for data input to said central processing unit, wherein said central processing unit comprises a hard disc drive according to Claim 26.

20 28. A non-linear trajectory generator comprising a non-linear controller as claimed in Claim 1 for controlling a simulated version of an actuator.

29. A non-linear trajectory generator according to Claim 28, further comprising a velocity limiter.

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30. A non-linear trajectory generator according to Claim 29, further comprising a limiter operable to restrict a difference between a reference trajectory and a signal representing an actual actuator position.