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(54) Title: SYSTEM AND METHOD FOR CORRECTING SCAN POSITION ERRORS IN AN IMAGING SYSTEM

(57) Abstract: Embodiments of the invention provide systems and methods for correcting scan position errors in an imaging system. In one embodiment of the present invention, the method includes determining an image beam velocity error as a function of a position within a scan line of an image, and using the image beam velocity error to determine a plurality of pixel clock frequencies to be respectively applied to a plurality of positions within the scan line.



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SYSTEM AND METHOD FOR CORRECTING SCAN POSITION ERRORS IN AN IMAGING SYSTEM

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention generally relates to systems and methods for correcting scan position errors in an imaging system.

Background Description

FIG. 1, generally at **100**, is an illustration of a known flat field scanning system in which images can be plotted on a suitable medium, such as photosensitive material **132**, from an electrical signal, such as an externally applied video signal **90** of the image. Video signal **90** modulates a power source such as laser driver **95**, which, in turn, drives light source **110**. Light source **110** converts video signal **90** into an image modulated visible or infrared light output that is collimated by lens **112** to form an image modulated light beam **115**. Image modulated light beam **115** may be visible, infrared, or ultraviolet light and is generated by a laser, such as a helium neon laser or a semiconductor laser diode. Image modulated light beam **115** is deflected by a rotatable mirror **120** having, for example, a 45 degree surface **150**, towards a focusing lens (or scan lens) system **125**, which focuses deflected light beam **145** into an image point on photosensitive material **132**. A high-speed motor **142** drives rotatable mirror **120** about a rotation axis **140**.

As mirror **120** is rotated, beam **145** passes through scan lens system **125**, causing a focused spot to move in a raster-like fashion along an imaging line **135** on material **132**. The scan angles θ that are swept out during imaging by the surface **150** span a range from approximately -32° to $+32^\circ$. During this period, information contained in beam **145** exposes photosensitive material **132** in a sweep or scan-like manner. To produce the sweeping action of beam **145**, motor **142** rotates mirror **120** at a pre-determined angular velocity. For a high-resolution scan, imaging line **135** is very fine (e.g., less than about 1/1000 of an inch wide). To scan an image field rapidly with such fine scan-beams, motor **142** typically turns mirror **120** at a high frequency (e.g., 20,000 revolutions per minute (RPM)).

Images are plotted by repetitive deflection of beam **145** where, for example, imaging line **135** is plotted in one beam deflection. Images are plotted as a successive plotting of

imaging lines **135**, wherein each imaging line **135** is made up of image elements known as pixels. More particularly, to expose the second dimension of photosensitive material **132**, photosensitive material **132** can be translated in a direction perpendicular to imaging line **135** using techniques known in the art, such as a standard capstan roller. Alternatively, focused beam **158** can be translated perpendicular to imaging line **135** on photosensitive material **132** by, for example, using another movable mirror (not shown) positioned between scan lens system **125** and photosensitive material **132** to redirect beam **158**. In addition, scan lens system **125** can be translated in a direction perpendicular to imaging line **135** using techniques known in the art, such as a flat bed

Scan lens system **125** is constructed and arranged to focus beam **145** during scanning at all points along imaging line **135**. In particular, scan lens system **125** can be an f-theta lens, i.e., it maintains the relationship $Y=f\times\theta$, where f is the effective focal length of the system, θ is the scan angle, and Y is the distance of the imaged object along imaging line **135** from optical axis **98**. An f-theta lens ensures that the scanning speed of beam **145** across the flat image field on photosensitive material **132** is uniform for a constant angular velocity of rotatable mirror **120**.

In a scan lens system, such as scan lens system **125**, that uses an f-theta lens, position errors occur when image pixels are not located at their ideal position on photosensitive material **132**. For example, on imaging line **135**, a pixel intended for position **135a** may actually appear at position **135b**. The distance between the actual position **135b** and the intended position **135a** is the position error. Sources of position error(s) can include: (a) scan lens system **125** design and/or assembly; (b) scan lens system **125** tilt (the scan lens system **125** is not ideally located in the path of beam **145**); and (c) contributions of other optical and/or mechanical components positioned in the laser beam path that have non-ideal characteristics, and/or a non-ideal location of other optical and/or mechanical components in the laser beam path.

While position error is generally predictable for a given scan lens system **125** design, the actual position error produced by the scan lens system **125** can deviate from the predicted position error due, for example, to lens manufacturing tolerances and/or variations in other system components and alignments. It should be understood that position errors can also occur, for example, in drum type imaging systems, where such position errors are typically

caused because the drum surface, or sections thereof, are not ideally located at the laser beam path.

One or more embodiments of the present invention is directed to systems and methods for reducing or eliminating position errors that occur in imaging systems.

SUMMARY OF THE INVENTION

In accordance with one embodiment of the present invention, a method of correcting scan position errors in an imaging system that can utilize a direct digital synthesizer (DDS) unit includes the steps of computing a nominal frequency tuning word, determining a number of corrections per scan line of an image, determining a next correction position, determining an image beam velocity error for the next correction position, determining a corrected frequency tuning word, and utilizing the corrected frequency tuning word to determine a pixel clock frequency for the next correction position.

Computing a nominal frequency tuning word can include the steps of generating a nominal linear scanning beam velocity by multiplying a rotational speed of an imaging system motor by an effective focal length of a scan lens assembly of the imaging system, and generating a nominal pixel clock frequency by multiplying the nominal linear scanning beam velocity by an image resolution. In addition, a formula can be applied relating an output frequency of a DDS unit, a system clock frequency of the DDS unit, and the nominal frequency tuning word, and the formula can be solved for the nominal frequency tuning word.

Also in accordance with an embodiment of the present invention, determining the number of corrections per scan line can include determining a frequency at which a memory of the DDS unit is driven, generating a first value by multiplying the frequency by the width of an image line, generating a second value by dividing the first value by the nominal linear scanning beam velocity, generating a third value by dividing the second value by the number of memory locations, generating a fourth value by rounding up of the third value to a nearest integer value, and determining a number of corrections per scan line of an image by dividing the second value by the fourth value.

The next correction position can be determined by first determining a correction spacing. The correction spacing, in turn, can be determined by generating a fifth value by multiplying the fourth value by the nominal linear scanning beam velocity to produce a product, and dividing the product by the frequency at which a memory of the DDS unit is driven. The next correction position can then be determined by adding the correction spacing to the current correction position.

The image beam velocity error at the next correction position can be determined by taking a derivative with respect to time of an image beam position error profile, and evaluating the derivative at the next correction position, thereby generating the image beam velocity error.

The corrected frequency tuning word can be determined by multiplying the nominal frequency tuning word by the sum of the image beam velocity error and 1.0, for the next correction position. The pixel clock frequency can be determined by accumulating phase information contained in the corrected frequency tuning words.

In another embodiment of the present invention, a method for correcting scan position errors in an imaging system can include determining an image beam velocity error as a function of a position within a scan line of an image, and using the image beam velocity error to determine a plurality of frequency tuning words used to generate a plurality of pixel clock frequencies to be respectively applied to a plurality of positions within the scan line. The method can further include performing an imaging operation in accordance with the plurality of pixel clock frequencies.

In yet another embodiment of the present invention, a system for correcting scan position error in an imaging system includes firmware for computing a nominal frequency tuning word used to control a rate of accumulation in a phase accumulator of a direct digital synthesizer (DDS) unit, determining a number of corrections per scan line of an image, determining a next correction position, determining an image beam velocity error for the next correction position, and determining a corrected frequency tuning word. The DDS unit utilizes the corrected frequency tuning word to determine a pixel clock frequency for the next correction position. The system can be, for example, an f-theta imaging system and/or a drum type imaging system.

In this system, the number of corrections per scan line can be determined by determining a frequency at which a memory of the DDS unit is driven, generating a first value by multiplying the frequency by the width of an image line, generating a second value by dividing the first value by a nominal image beam velocity, generating a third value by dividing the second value by a number of memory locations associated with the DDS unit, generating a fourth value by rounding up of the third value to a nearest integer value, and

determining a number of corrections per scan line of an image by dividing the second value by the fourth value.

The system can include a laser for performing an imaging operation in accordance with the pixel clock frequency. The system can also include non-volatile storage containing firmware to perform at least the computing, a microprocessor to execute the firmware, and an interface unit to provide the corrected frequency tuning word to the DDS unit.

In still another embodiment of the present invention, a system for correcting scan position errors in an imaging system can include firmware for determining a plurality of image beam velocity errors as a function of a plurality of respective positions within a scan line of an image, and a direct digital synthesizer unit for utilizing data representative of the plurality of the image beam velocity errors to determine a plurality of pixel clock frequencies to be respectively applied to the plurality of respective positions within the scan line. The system can further include a laser for performing an imaging operation in accordance with the plurality of pixel clock frequencies. In addition, the system can include a microprocessor to execute the firmware, and an interface unit to provide the data representative of the plurality of beam velocity errors to the circuitry.

Determining the image beam velocity error can include taking a derivative with respect to time of an image beam position error profile, and evaluating the derivative at a next image beam correction position, thereby generating the image beam velocity error.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description of the present application showing various distinctive features may be best understood when the detailed description is read in reference to the appended drawings in which:

FIG. 1 is an illustration of a known flat field scanning system.

FIG. 2 is a block diagram of an exemplary system for correcting position errors in accordance with an embodiment of the present invention.

FIG. 3 is a flow diagram in accordance with an exemplary embodiment of the present invention, illustrating a method of fitting a polynomial to position error data.

FIG. 4 is an exemplary position error profile.

FIG. 5 is a flow diagram in accordance with an exemplary embodiment of the present invention, illustrating a method of reducing or eliminating position error.

FIG. 6 is an exemplary velocity error profile.

DESCRIPTION OF THE INVENTION

FIG. 2, generally at **200**, is a block diagram of an exemplary system for correcting scan position errors in accordance with an embodiment of the present invention. FIG. 2 can thus be used, for example, in conjunction with system **100** shown in FIG. 1 to correct scan position errors. In particular, video signal **90** (FIG. 1) can be generated as a function of pixel clock frequency **216** (FIG. 2). As used herein, position error can be defined as the difference between the intended pixel position **135a** and the actual pixel position **135b**. Position error can be treated as a signed value, since the sign (positive or negative) can be used to indicate the direction of the error, and therefore the polarity of the required correction.

System **200** control is generally implemented and maintained by microprocessor unit **206** which, in one or more embodiments of the present invention, executes firmware stored in, for example, non-volatile storage **207**. Microprocessor unit **206** can execute the firmware stored in non-volatile storage **207** to control the functions of system **100** that are not controlled by dedicated hardware. For purposes of position error correction, computations can be performed by microprocessor **206**. Microprocessor unit **206** can also control other system functions, such as sequencing of motors, monitoring of sensors, user interface, and/or communication with a host computer (not shown).

In one or more embodiments of the present invention, non-volatile storage **207** can be, for example, standard flash memory that stores the firmware, and Static Random Access Memory (SRAM) that stores system **100** parameters such as laser power, optical efficiency of scan lens system **125** (i.e., the laser energy output from scan lens system **125** divided by the laser energy input to scan lens system **125**), and scan position error data, as will be described herein. SRAM can be battery backed-up SRAM.

Interface **205** includes logic (e.g., circuitry) that enables microprocessor **206** to access and control direct digital synthesis (DDS) unit **201**, phase locked loop (PLL) **202**, and frequency divider **204**. Interface **205** can include a standard parallel to serial converter that allows microprocessor **206** data to be serially transmitted to DDS unit **201**. Interface **205** can be implemented, for example, as a standard Field Programmable Gate Array (FPGA) device. For example, interface **205** can be implemented as device XC2S200E from Xilinx, Inc., San Jose, CA. The Spartan-III 1.8V FPGA Family: Complete Data Sheet, dated July 28, 2004, Xilinx, Inc., San Jose, CA, is incorporated herein by reference. Frequency divider **204** can be

implemented as device SY100S834L from Micrel Incorporated, San Jose, CA. The Micrel Incorporated SY100S834, SY100S834L ($\div 1$, $\div 2$, $\div 4$) OR ($\div 2$, $\div 4$, $\div 8$) Clock Generation Chip, Rev. F, Amendment /O, September 1999, is incorporated herein by reference. Microprocessor **206** can be implemented, for example, as device N80C196NT from Intel Corporation, Santa Clara, CA.

Generally, a DDS unit, such as DDS unit **201**, has the following basic blocks (not shown): a phase accumulator, a phase to amplitude converter (conventionally a sine ROM), a digital to analog converter, and a filter. A standard DDS unit works on the principle that a digitized waveform of a given frequency can be generated by accumulating phase changes at a higher frequency. The phase value stored in an input frequency register is added to the value in the phase accumulator once during each period of the system clock. The resulting phase value (from 0 to 2π) is then applied to the sine lookup once during each clock cycle. The lookup converts the phase information to its corresponding sine amplitude. A digital to analog converter converts the sine amplitude information into a sinusoidal type signal. The sinusoidal type signal can be filtered and applied to a comparator to generate a digital signal at the output of the DDS unit. A DDS unit **201** such as model AD9954 from Analog Devices, Inc., Norwood, MA, can be used with an external filter (not shown). Analog Devices 400 MSPS 14-Bit, 1.8 V CMOS Direct Digital Synthesizer AD9954 Product Data Sheet, Rev. 0, dated 2003, is incorporated herein by reference.

Output frequency **208** of DDS unit **201**, which can be in the range, for example, of 50-66 MHz, is programmable (i.e., tunable) and can be a function, for example, of a 32 bit number, known as a frequency tuning word, that is applied to the phase accumulator of DDS unit **201**. As used herein, a frequency tuning word is used to control the rate of accumulation in the phase accumulator of DDS unit **201**. A series of frequency tuning words can be preloaded into DDS unit **201**, and stored in its internal memory. This series of frequency tuning words can be used to correct position errors. A method for generating the frequency tuning words, and how they are used to correct position errors, will be discussed herein.

Output frequency **208** is converted to a higher frequency **212** by PLL **202**. A PLL **202**, such as device SY89421V from Micrel Incorporated, San Jose, CA, can be used. The Micrel Incorporated SY89421V, 5V/3.3V, High-Performance, Phase Locked Loop Data Sheet, dated 2000, is incorporated herein by reference.

PLL **202** can operate in different modes and is controlled by one or more signal **222**, received from interface unit **205**. Signal **222** can represent parameters, such as multiplication factors, internal to PLL **202**, to produce a higher output frequency **212**. In at least one embodiment of the present invention, PLL **202** generates a frequency **212** in the range, for example, of 600 MHz to 1 GHz.

PLL **202** output frequency **212** is supplied to synchronization unit **203** and frequency divider **204**. A synchronization unit **203**, such as device MC100EP142 from ON Semiconductor Corp. (Semiconductor Components Industries, LLC), Phoenix, AZ, can be utilized. The ON Semiconductor Corp. (Semiconductor Components Industries, LLC), MC10EP142, MC100EP142 3.3V / 5V, ECL 9-Bit Shift Register Data Sheet, November, 2004 - Rev. 13, is incorporated herein by reference. An external start of scan signal **214**, which can be generated from a standard optical encoder (not shown) of motor **142**, is also supplied to synchronization unit **203**. Start of scan signal **214** can be a synchronization pulse that indicates the start position of a laser beam sweep. Start of scan signal **214** is generated once per beam deflection sweep (i.e., once for each imaging line **135**) at a frequency of, for example, 533 Hz. Start of scan signal **214** can generally range from 100 Hz to 1200 Hz depending, for example, on motor **142** speed, which in turn can depend, for example, on image resolution, laser **95** power, and media exposure requirements. Another type of external sensor that can be used is a standard photodetector device positioned in the path of beam **158**, prior to image line **135**.

Synchronization unit **203** provides as output a synchronized start of scan signal **210** that is synchronized to frequency **212**. Synchronized start of scan signal **210** is provided as input to frequency divider **204** and interface **205**. Synchronized start of scan signal **210** causes frequency divider **204** to start by releasing, for example, a standard CLEAR control input. Frequency divider **204** divides frequency **212** to generate pixel clock frequency **216**. Interface **205** provides control signals **221** to enable microprocessor **206** control over selection of the divider ratio utilized by frequency divider **204**, in order to achieve a desired pixel clock frequency **216**. The value of the divider ratio is determined by microprocessor **206**, as will be discussed herein.

Synchronization unit **203** and frequency divider, **204** are thus utilized to generate a desired pixel clock frequency **216** that is synchronized to start of scan signal **214**. This is

desirable in order to ensure that the first (and other) pixel(s) is at the same start position from scan line to scan line, with a precision of one cycle of output frequency **212**. In one or more embodiments of the present invention, pixel clock frequency **216** is in the range, for example, of 80 MHz to 250 MHz.

Frequency tuning words are determined by executing an algorithm, prior to imaging operations, as will be explained in connection with FIG. 3 and FIG. 5. The algorithm can be implemented in firmware, which can be stored in non-volatile storage unit **207**, and executed by microprocessor **206**.

Prior to imaging operations, frequency tuning words, as part of data **220**, are transmitted from microprocessor **206** to interface unit **205**, and serially clocked into the internal memory of DDS unit **201**. In addition, control register data such as the frequency of DDS unit **201** clock and the number of DDS unit **201** clock cycles per correction, can also be transmitted as data **220** and serially clocked into DDS unit **201**. Interface unit **205** implements the parallel to serial conversion that allows the various selected microprocessor **206** data to be serially input into DDS unit **201**. This allows microprocessor **206** to configure DDS unit **201**, prior to imaging, such that during imaging DDS unit **201** is configured to adjust pixel clock frequency **216** in the manner as described below.

During an imaging operation, synchronized start of scan signal **210** and pixel clock frequency **216** are provided to interface **205**, which generates update signal **218**. Update signal **218**, which can be generated once per beam sweep, prompts DDS unit **201** to begin sequentially applying the frequency tuning words (that are included in data **220** and pre-stored in DDS unit **201** memory) to the internal accumulator of DDS unit **201**. DDS unit **201** sequentially applies the frequency tuning words as beam **158** is swept across imaging line **135**. As each frequency tuning word is sequentially supplied to the internal accumulator of DDS unit **201**, DDS unit **201** adjusts (i.e., changes the frequency of) output frequency **208** during the beam sweep. Output frequency **208** can be changed at a rate based on, for example, the amount of random access memory (RAM) in DDS unit **201** and an algorithm stored, for example, in non-volatile storage **207**, as will be explained in connection with FIG. 5.

As output frequency **208** is adjusted during the beam sweep, PLL **202** output frequency **212** is also adjusted (i.e., changed) in a similar (e.g., linear) manner as it is

responds to output frequency **208**. Similarly, pixel clock frequency **216** is also adjusted (i.e., changed) as it tracks PLL **202** output frequency **212**. The manner in which pixel clock frequency **216** is adjusted is therefore controlled by the frequency tuning words in DDS unit **201** memory.

During a beam sweep that would generate imaging line **135** (FIG. 1), the placement of pixels on imaging line **135** is a function of pixel clock frequency **216**. By adjusting pixel clock frequency **216**, under control of the frequency tuning words in DDS unit **201** memory as described above, the pixel spacing is adjusted during imaging on photosensitive material **132**. Pixel spacing is adjusted to reduce or eliminate pixel placement position errors caused by, for example, the optical components in imaging system **100**. We have discovered that although position errors may exhibit variations in scale, rotation, and symmetry, they generally vary slowly and smoothly across a scan line, such as imaging line **135**. In one or more embodiments of the present invention, position errors are corrected to within 50 microns or less, which is a reduction that generally ranges from a factor of two to at least an order of magnitude.

System **200** can be implemented at a variety of different spinning mirror **120** rotation speeds, image resolutions and image locations, and in various combinations thereof. In one embodiment of the present invention, system **200** can be used to optimally correct for media and corresponding images that vary continuously in size from 4.5 inches to 45 inches and/or generate images of resolutions of about 6000 dots/inch. Other embodiments of the present invention can be used with images whose resolutions vary from one image to the next.

As stated previously, the frequency tuning words are determined by a program stored as firmware in non-volatile storage **207**, to be executed by microprocessor **206**. The program algorithms will now be explained in connection with Figures 3 and 5.

FIG. 3, generally at **300**, is a flow diagram in accordance with an exemplary embodiment of the present invention, illustrating a method of fitting a polynomial to position error data. The method of FIG. 3 is generally performed at system **200** startup. FIG. 4, generally at **400**, is an exemplary position error profile, where the x-axis represents the expected (intended) pixel position **135a** of the target pixel with respect to a reference point, and the y-axis represents the error at that position (i.e., the difference between the intended pixel position **135a** and the actual pixel position **135b**).

In general, polynomial **402** takes the following form:

$$y = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5$$

The order of polynomial **402** is generally dependent on the scan lens system **125** and system **100** design, and will typically range from 2nd order to 6th order. The polynomial “fitting” can be accomplished using, for example, a standard least squared error algorithm to find the coefficients, $a_0 - a_5$. In order to accommodate alternate scan lens system **125** and/or system **100** designs, a method in accordance with the present invention iteratively attempts to fit a polynomial **402** (FIG. 4) to the position error data, using a progressively larger number of coefficients until, for example, a polynomial **402** is determined that has a least squared error that satisfies acceptability criteria with respect to position error. In most cases, the polynomial fitting can be accomplished using IEEE standard 754 single or double precision floating point math. Some cases, however, may require the use of arbitrary precision math in order to satisfy desired acceptability criteria.

Polynomial **402** coefficients can be stored, for example, in microprocessor memory, and be recomputed if position error data changes. For example, prior to each image, the expected and actual position values are checked against the values that were used to compute the polynomial coefficients at startup. If any of the position values have changed, the algorithm of Figure 3 can be run (again) to determine a new set of coefficients.

Returning now to FIG. 3, initially, at step **302**, actual and expected pixel position data is determined. For example, an image containing targets in known locations can be plotted by an imaging system, such as system **100**, and the position of each target is measured by, for example, a technician. The technician then enters the position data and position error data for each target into system **200** via, for example, terminal **230**, as pairs of values: an expected position and an actual position. As part of this process, data may be collected by a system such as the VideoMic[®], manufactured by Operations Technology, Inc, Blairstown, NJ. Such data may be provided to non-volatile storage **207** using, for example, terminal **230**. Terminal **230** can be a standard keyboard and monitor used in connection with a general purpose computer. Microprocessor **206** writes the position data and position error data into non-volatile storage **207**.

When system **200** is started, at step **304** microprocessor **206** reads the expected and actual position data from non-volatile storage **207**. At step **306**, microprocessor **206** computes the position error of each target and creates a set of (x,y) pairs with, for example, x representing the expected position of the target and y representing the error at that position.

At step **308**, microprocessor **206** determines coefficients of a polynomial by attempting to fit the polynomial to the set of (x,y) values. The order of the required polynomial will generally depend on various criteria (discussed above), such as scan lens system **125** design, and range, for example, from 2nd order to 6th order.

At decision step **310**, microprocessor **206** determines if the error in fitting polynomial **402** to the measured data is acceptable. Acceptability criteria may be stored in non-volatile storage **207**. If, at decision step **310**, it is determined that the fitting error is not acceptable, then, at step **316**, the order of polynomial **402** is increased by increasing the number of coefficients. If, at decision step **310**, it is determined that the fitting error is acceptable, then, at step **312**, the coefficients are saved, for example, in microprocessor **206** memory, and the process terminates. In other embodiments of the present invention, coefficients can be stored in non-volatile storage, or in a combination of microprocessor **206** memory and non-volatile storage.

At decision step **314**, step **308** is repeated if the order of polynomial **402** is less than or equal to 6th order. If, at decision step **314** it is determined that polynomial **402** is a 7th order polynomial or greater, an error can be issued at step **318**. In one or more embodiments of the present invention, the error issued will typically indicate one or more errors in measurement or data entry. In other embodiments of the present invention, polynomial **402** can, however, be 7th order or greater depending, for example, on a need for increased accuracy.

Polynomial **402** thus represents the position error profile, and can be used to interpolate as many correction points desired between measurements. As is common in imaging systems such as system **100**, scan position errors tend to be greater near the start and end of imaging line **135**. Advantageously, in accordance with one or more embodiments of the present invention, polynomial **402** can be used, for example, to extrapolate corrections within as well as outside of the image area, without making measurements close to the edge of material **132**.

FIG. 5, generally at **500**, shows an exemplary method of reducing or eliminating position errors in accordance with an embodiment of the present invention. For each image plotted on material **132**, system **200** can determine, at step **501**, the rotational speed of motor **142** based on system parameters such as the optical efficiency of system **100**, the power of the beam emanating from laser driver **95**, and the exposure requirements of material **132**. As used herein, exposure requirements refer to the amount of light energy required to properly expose the photosensitive material. Unlike photographic film, where the exposure requirements are fairly standardized, the exposure requirements for printing plates can vary substantially. An operator will therefore generally provide instruction to a system (e.g., system **100**) indicating what type of plates are being used, and their exposure sensitivity, so that the firmware can initialize the system to deliver the correct amount of energy to the plate. System parameters can be stored in non-volatile storage **207**.

Multiplying the rotational speed of motor **142**, in radians per second, by the effective focal length of scan lens assembly **125** yields the nominal linear velocity of scanning beam **158** at image line **135**, hereafter referred to as beam velocity. The beam velocity, in inches per second, is then multiplied by the image resolution, in pixels per inch, to obtain the nominal pixel clock frequency **216**, expressed in pixels per second, or Hz. Microprocessor **206** then computes the nominal DDS frequency tuning word and PLL **202** multiplication factor required to generate this pixel clock frequency **216**. For example, PLL **202** multiplication factor can be selected by testing each of the possible multiplier values, starting with the smallest, until one is found that will give output frequency **208** that is within the input frequency range of the PLL **202** and within the output frequency range of the DDS unit **201**. Once a suitable multiplication factor is determined, the nominal frequency tuning word can be calculated according to a formula provided in a data sheet that will accompany a standard DDS unit **201** (e.g., a data sheet that is supplied with a DDS unit **201** such as the AD9954). For example, the Analog Devices 400 MSPS 14-Bit, 1.8 V CMOS Direct Digital Synthesizer AD9954 Product Data Sheet, Rev. 0, dated 2003, incorporated herein by reference, provides the following formulas:

$$f_o = (\text{FTW})(f_s)/2^{32} \quad \text{with } 0 \leq \text{FTW} \leq 2^{31}, \text{ and}$$

$$f_o = (f_s) \times (1 - (\text{FTW}/2^{32})) \quad \text{with } 2^{31} \leq \text{FTW} \leq 2^{32} - 1$$

Thus, for known output frequency **208** (corresponding to f_o) and the DDS system clock, SYSCLK (corresponding to f_s), the frequency tuning word (FTW) can be computed.

At step **502**, microprocessor **206** computes the number of corrections per scan line and the correction spacing, as will be described herein. As used herein, correction spacing is the linear distance between corrections on scan line 135. For example, if there are 128 corrections on an 8 inch horizontal image area, then the correction spacing is 1/16 inch. DDS unit **201** internal timing circuitry can generate a constant frequency clock known as SYNC_CLK, which is at $\frac{1}{4}$ of the SYSCLK frequency. The SYNC_CLK frequency is utilized to synchronize DDS unit **201** internal RAM timing with the DDS phase accumulator and update signal **218**. An integer value called RAMP_RATE defines the rate at which the internal RAM address will advance, expressed in SYNC_CLKs. In other words, the frequency tuning word values stored in DDS unit **201** internal RAM will be sequentially applied to the phase accumulator, with each one being used for the number of SYNC_CLKs defined by the RAMP_RATE value. The frequency of SYNC_CLK divided by the beam velocity and multiplied by the width of image line **135** yields the number of SYNC_CLKs per scan line. This value is then divided by the number (or size) of RAM locations (e.g., $2^{10} = 1024$ words of RAM), and rounded up to the next larger integer value to find the RAMP_RATE. The number of corrections per scan line is the number of SYNC_CLKs per scan line divided by the RAMP_RATE. The SYSCLK, SYNC_CLK and RAMP_RATE parameters are referenced in Analog Devices 400 MSPS 14-Bit, 1.8 V CMOS Direct Digital Synthesizer AD9954 Product Data Sheet, Rev. 0, dated 2003.

The correction spacing can be determined by multiplying the RAMP_RATE by the beam velocity, and dividing the product by the SYNC_CLK frequency. The distance between corrections is needed because DDS unit **201** is operating in the time domain, and sequencing through the RAM values at fixed time intervals as determined by the SYNC_CLK and RAMP_RATE. However, the measured position error data is in the spatial domain, so it is necessary to correlate the time domain information with the spatial domain in order to determine the error at each correction point, i.e., each time a new frequency tuning word is selected. The current position is set to zero, corresponding to the start of scan location.

At step **503**, the position of the next correction is determined by adding the correction spacing found in step **502** to the current position. This value becomes the new current position.

At step **504**, polynomial **402** is evaluated to find the error at the current position. Polynomial **402** represents the error in beam position. However, what is needed is the error in beam velocity. This is because the adjustable parameter is DDS unit **201** output frequency **208**, which is analogous to beam velocity. Evaluating the derivative of polynomial **402** with respect to time at the position determined in step **503** yields the error in beam velocity at that point. The beam velocity error is added to 1.0, and saved as a correction factor for this position. FIG. 6, generally at **600**, is an exemplary beam velocity profile, where the x-axis represents the expected position of the target pixel, and the y-axis represents the error in the actual beam velocity at that position. The beam velocity profile **602** can be determined by taking the derivative with respect to time of the position error profile of FIG. 4.

If, at decision step **505**, it is determined that system **200** has not computed correction factors for the number of corrections per scan line **135** determined in step **502**, the method returns to step **503** to calculate the next correction spacing. If at decision step **505**, it is determined that system **200** has computed correction factors for the number of corrections per scan line determined in step **502**, the method proceeds to step **506**.

At step **506**, each of the correction factors determined in step **504** is multiplied by the nominal frequency tuning word value determined in step **501** to produce respective corrected frequency tuning words. The resulting corrected frequency tuning words are then written into the DDS unit **201** memory at step **507**.

Other embodiments of the invention can include the following steps. Subsequent to applying the correction algorithm as described in FIG. 5, a material **132** is imaged, and measured for scan position error as previously described. While position errors will be reduced, they may not be reduced to zero. An approach to reducing the residual error is to perform a second pass correction. In particular, the second pass correction is performed by modifying the frequency tuning words used in the first pass, based on the residual measured errors. Thus, for each correction point, the original measured actual position value is adjusted by the residual error at that point, either adding or subtracting depending on the direction of the additional residual error. These adjusted values are then entered as the

correction data used to compute new frequency tuning words. This process could be performed iteratively, with each repetition further reducing position errors.

Other embodiments of the invention can be used to correct for scan position errors in an input scanning system. For these systems, position error data would be generated by scanning a known accurate target and processing the scanned image data. The position error data is then entered and used in the same manner as in the imaging system application.

The many features and advantages of the invention are apparent from the detailed specification, and thus, it is intended to cover all such features and advantages of the invention which fall within the true spirit and scope of the invention. Further, since numerous modifications and variations will readily occur to those skilled in the art, it is not desired to limit the invention to the exact construction and operation illustrated and described, and accordingly, all suitable modifications and equivalents may be resorted to, falling within the scope of the invention. While the foregoing invention has been described in detail by way of illustration and example of preferred embodiments, numerous modifications, substitutions, and alterations are possible. For example, since scan position errors can also occur in drum type imaging systems, where scan position errors are typically caused because the drum surface, or sections thereof, are not ideally located at the laser beam path, the present invention contemplates that one or more embodiments thereof can also be utilized in connection with drum-type imaging systems.

Claims

Having thus described our invention, what we claim as new and desire to secure by Letters Patent is as follows:

1. A method of correcting scan position errors in an imaging system comprising a direct digital synthesizer (DDS) unit, comprising:
 - (a) computing a nominal frequency tuning word used by the DDS unit;
 - (b) determining a number of corrections per scan line of an image;
 - (c) determining a next correction position;
 - (d) determining an image beam velocity error for the next correction position;
 - (e) determining a corrected frequency tuning word;
 - (f) utilizing the corrected frequency tuning word to determine a pixel clock frequency for the next correction position.
2. The method according to claim 1, wherein computing a nominal frequency tuning word step (a) comprises:
 - (g) generating a nominal linear scanning beam velocity by multiplying a rotational speed of an imaging system motor by an effective focal length of a scan lens assembly of the imaging system;
 - (h) generating a nominal pixel clock frequency by multiplying the nominal linear scanning beam velocity by an image resolution; and
 - (i) applying a formula relating an output frequency of the DDS unit, a system clock frequency of the DDS unit, and the nominal frequency tuning word; and
 - (j) solving the formula for the nominal frequency tuning word.

3. The method according to claim 2, wherein determining the number of corrections per scan line step (b) comprises:

- (k) determining a frequency at which a memory of the DDS unit is driven;
- (l) generating a first value by multiplying the frequency of step (k) by the width of an image line;
- (m) generating a second value by dividing the first value of step (l) by the nominal linear scanning beam velocity generated in step (g);
- (n) generating a third value by dividing the second value of step (m) by a number of memory locations associated with step (k);
- (o) generating a fourth value by rounding up of the third value of step (n) to a nearest integer value; and
- (p) determining a number of corrections per scan line of an image by dividing the second value of step (m) by the fourth value of step (o).

4. The method according to claim 3, wherein determining a next correction position step (c) comprises:

determining a correction spacing comprising:

- (q) generating a fifth value by multiplying the fourth value of step (o) by the nominal linear scanning beam velocity to produce a product, and dividing the product by the frequency in step (k); and
- (r) adding the fifth value to a current correction position.

5. The method according to claim 4, wherein determining the image beam velocity error at the next correction position step (d) comprises:

- (s) taking a derivative with respect to time of an image beam position error profile; and
- (t) evaluating the derivative at the next correction position, thereby generating the image beam velocity error.

6. The method according to claim 5, wherein determining a corrected frequency tuning word step (e) comprises the step multiplying the nominal frequency tuning word by the sum of the image beam velocity error and 1.0, for the next correction position.
7. The method according to claim 6, wherein the pixel clock frequency is determined by accumulating phase information contained in the corrected frequency tuning words.
8. The method according to claim 1, further comprising the step of repeating steps (c) through (f) for each correction per scan line of the image determined in step (b).
9. A method of correcting scan position errors in an imaging system, comprising:
 - determining an image beam velocity error as a function of a position within a scan line of an image; and
 - using the image beam velocity error to determine a plurality of frequency tuning words used to generate a plurality of pixel clock frequencies to be respectively applied to a plurality of positions within the scan line.
10. The method according to claim 9, further comprising the step of performing an imaging operation in accordance with the plurality of pixel clock frequencies.
11. A system for correcting scan position error in an imaging system, comprising:
 - firmware for:
 - computing a nominal frequency tuning word used to control a rate of accumulation in a phase accumulator of a direct digital synthesizer (DDS) unit;
 - determining a number of corrections per scan line of an image;
 - determining a next correction position;
 - determining an image beam velocity error for the next correction position; and
 - determining a corrected frequency tuning word;
 - wherein the DDS unit utilizes the corrected frequency tuning word to determine a pixel clock frequency for the next correction position.

12. The system of claim 11, wherein the system comprises an f-theta imaging system.
13. The system of claim 11, wherein the system comprises a drum type imaging system.
14. The system according to claim 11, wherein determining the number of corrections per scan line comprises:
- determining a frequency at which a memory of the DDS unit is driven;
 - generating a first value by multiplying the frequency by the width of an image line;
 - generating a second value by dividing the first value by a nominal image beam velocity;
 - generating a third value by dividing the second value by a number of memory locations associated with the DDS unit;
 - generating a fourth value by rounding up of the third value to a nearest integer value; and
 - determining a number of corrections per scan line of an image by dividing the second value by the fourth value.
15. The system according to claim 11, further comprising a laser for performing an imaging operation in accordance with the pixel clock frequency.
16. The system according to claim 11, further comprising:
- non-volatile storage containing firmware to perform at least the computing step;
 - a microprocessor to execute the firmware; and
 - an interface unit to provide the corrected frequency tuning word to the DDS unit.

17. A system for correcting scan position errors in an imaging system, comprising:
firmware for determining a plurality of image beam velocity errors as a function of a plurality of respective positions within a scan line of an image; and
a direct digital synthesizer unit for utilizing data representative of the plurality of the image beam velocity errors to determine a plurality of pixel clock frequencies to be respectively applied to the plurality of respective positions within the scan line.
18. The system according to claim 17, further comprising a laser for performing an imaging operation in accordance with the plurality of pixel clock frequencies.
19. The system according to claim 17, further comprising:
a microprocessor to execute the firmware; and
an interface unit to provide the data representative of the plurality of beam velocity errors to the direct digital synthesizer.
20. The system according to claim 17, wherein determining the image beam velocity error comprises:
taking a derivative with respect to time of an image beam position error profile; and
evaluating the derivative at a next image beam correction position, thereby generating the image beam velocity error.

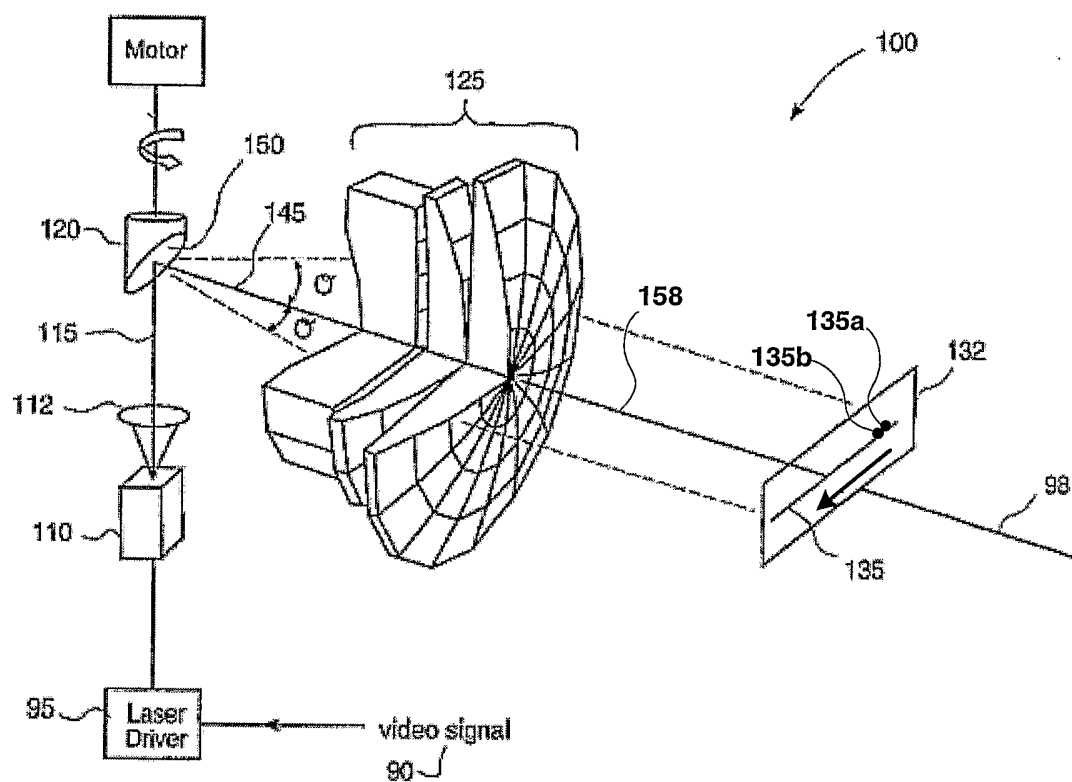


FIG. 1

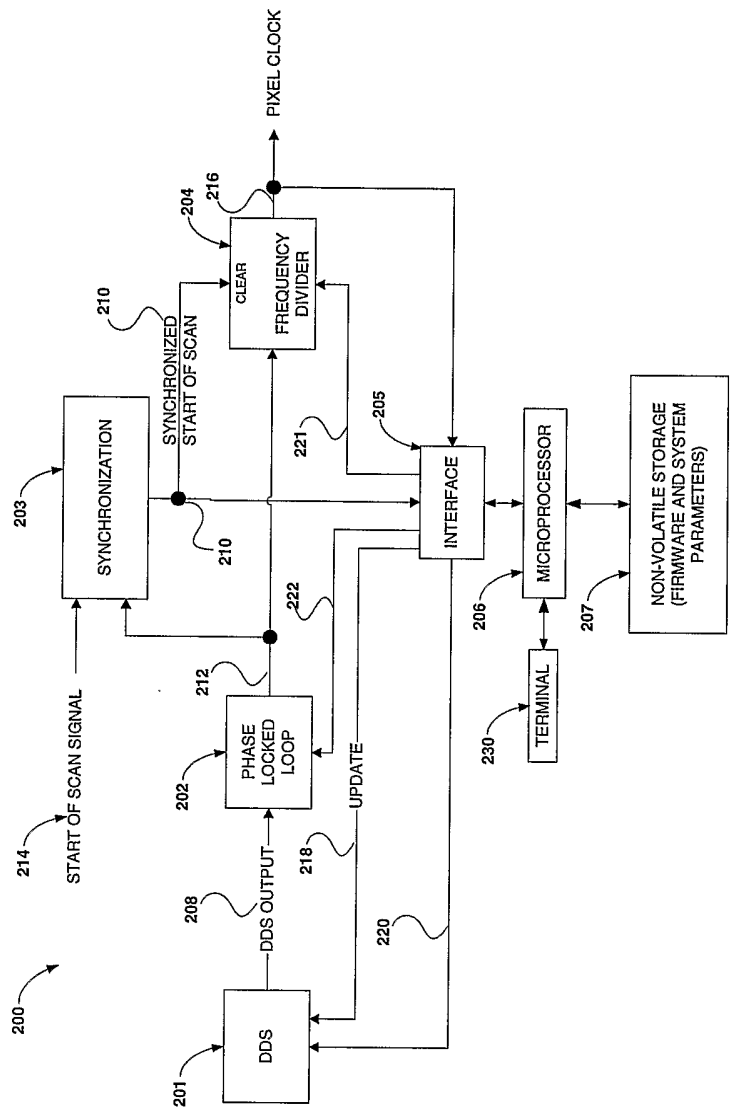


FIG. 2

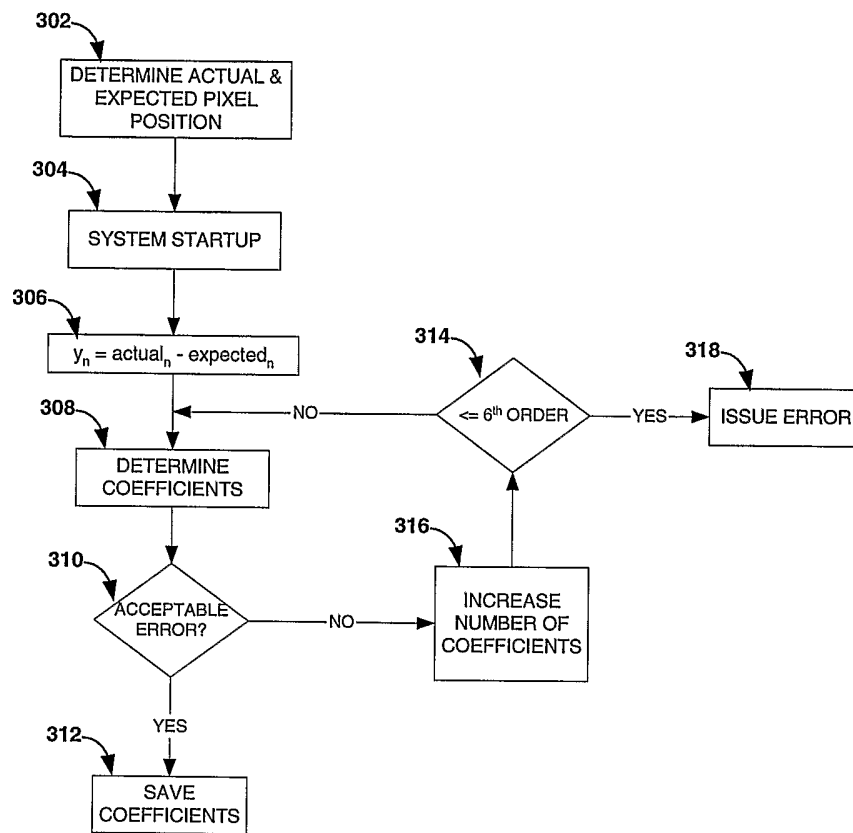


FIG. 3

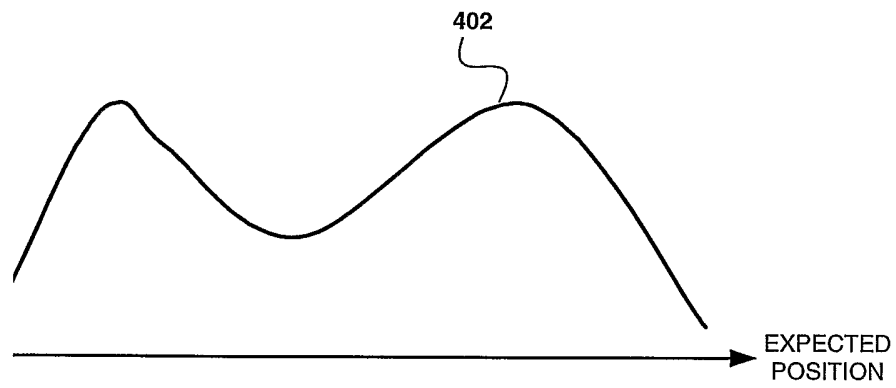


FIG. 4

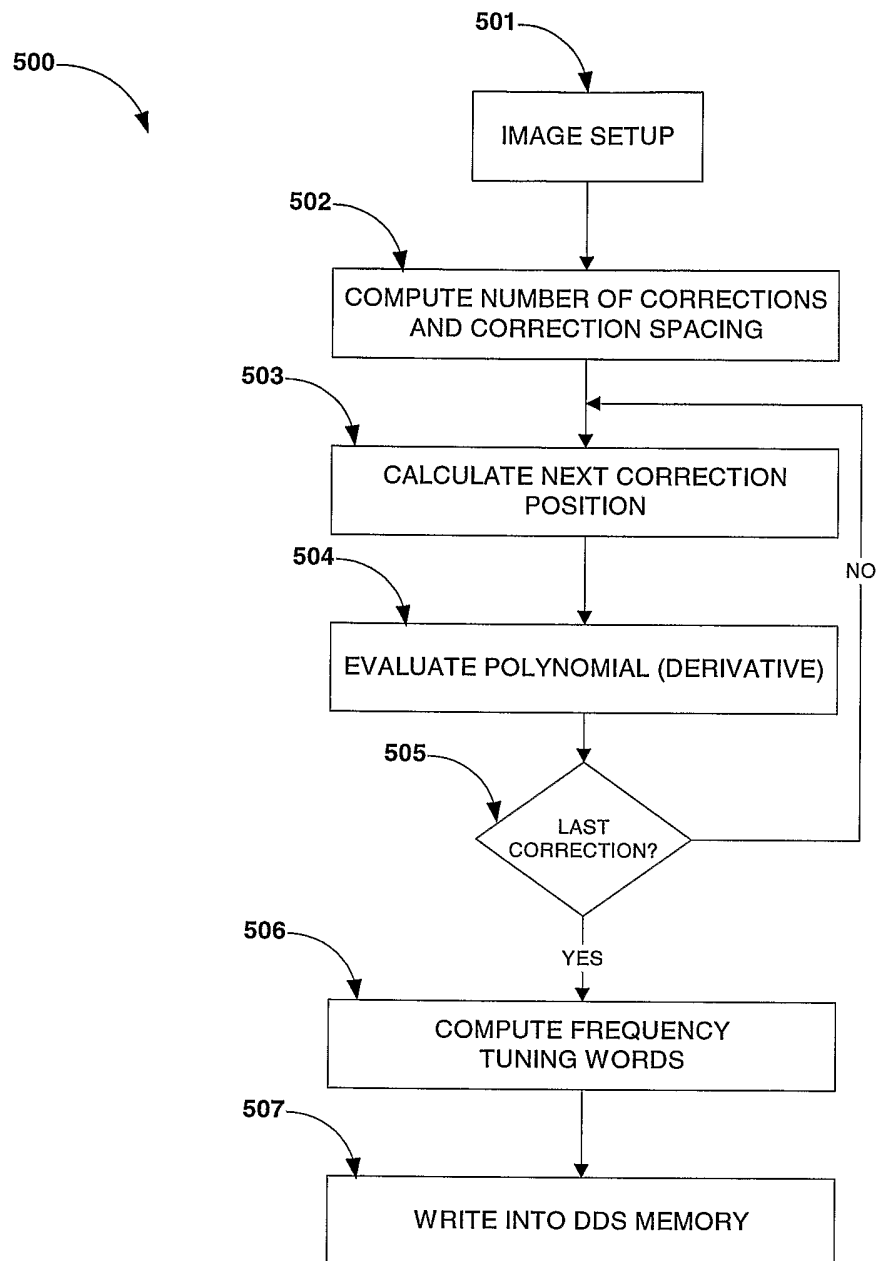
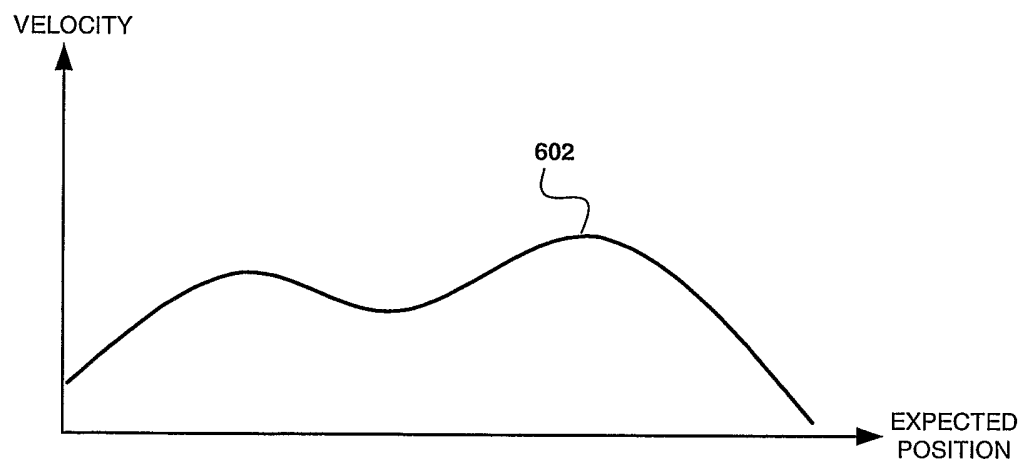


FIG. 5

**FIG. 6**