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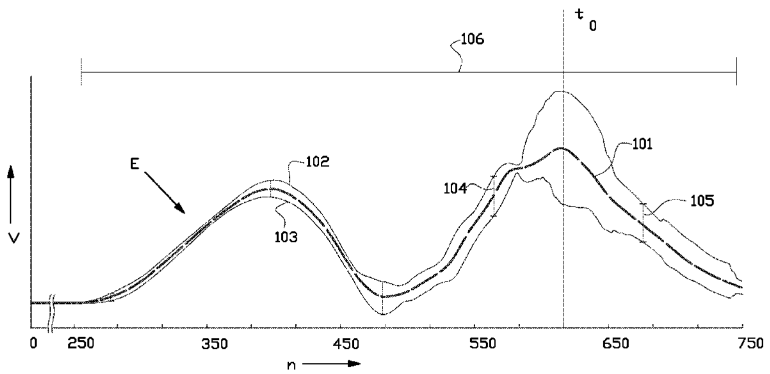


FIG. 1A

(57) **Abstract**: The invention relates to a device and method for motion capture and analysis of motion of an object, in which an adaptive envelope derived from multiple motion measurements is used for determining the extent to which a further motion measurement conforms to an envelope or section thereof derived from the earlier multiple motion measurements. The invention further provides a method for adaptively converging the envelope towards a non- predetermined envelope in dependence on a number of consecutive motion measurements made with the object, thus allowing subjective or tailor made improvement and/or monitoring of further motions.

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# Device and method for motion capture and analysis

## BACKGROUND

The invention relates to a method and device for motion capture and analysis. In particular the present invention relates to a method and device for motion capture and analysis of golf swing motions using accelerometers.

Systems for motion analysis have been known in the art, for example from International Application WO 02/35184, which describes a system for measuring the motion of a sporting equipment, the system comprising:

a motion sensing system in communication with said sporting equipment to measure motion parameters, wherein said motion sensing system comprises: at least one of at least one accelerometer and at least one gyroscope,

a command station comprising a data acquisition system to process said measured motion parameters and produce data, wherein said data acquisition system compares said produced data to previously stored data.

A disadvantage of such a system is that once an athlete has trained a motion, e.g. a golf swing, to conform to the motion parameters described in the previously stored data, the system offers no hints for further improvement. Moreover, WO 02/35184 fails to disclose the manner in which the measured motion parameters are processed, or how these parameters are compared to previously stored data.

United States Application US 2009/0005188 discloses a method for analysis of golf swings by comparing torque-curves associated with executing a golf swing. The torque curves are derived from recorded video images of the swing. In an embodiment an optimum curve is compared with curves of a subsequently performed swing, for diagnosing said subsequently performed golf swing. The optimum curve may have been derived from swings that were performed earlier. When multiple observed torque curves do not vary wildly it can be diagnosed that the stability of the corresponding swings is high.

It is an object of the present invention to provide an improved method and device for motion capture and analysis.

SUMMARY OF THE INVENTION

To this end the invention provides a device according to claim 1 and a method according to claim 8. Advantageous embodiments are described in the dependent claims.

The present invention provides a method for capture and analysis of a repeated motion of an object, comprising a learning phase comprising the steps of:

- repeatedly performing a motion with or by said object,

- obtaining multiple corresponding motion measurements, each motion measurement comprising N motion signals over time based on signals from motion sensors attached to said object,

- determining, for each of the multiple motion measurements, a first anchor point representative of a first characteristic point in the corresponding motion measurement,

- centering the respective first anchor points of the multiple motion measurements at a first common anchor point,

- calculating, from the multiple centered motion measurements, one or more predetermined sections of N envelopes defining ranges for the corresponding N motion signals. Preferably, each of said sections defines a time range relative to the first anchor point, and each of said N envelopes comprises an upper bound defined as a maximum of the corresponding signals, and a lower bound defined as a minimum of the corresponding signals.

During the learning phase, N, being one or more, envelopes or sections thereof are constructed representative of a range of motions. Each of these N envelopes is specifically tailored to the multiple motions that have been performed with the object, and may thus define asymmetrical upper- and lower- limits. As the signals measured over time in a motion measurement may not all be relevant, the predetermined envelope sections are preferably chosen to cover only relevant portions of time of a motion signal. Said relevant portions are typically application dependent. In golf for instance, only parts of the motion signals measured within about 2 seconds on either side of the time of impact will typically be interesting; motion signals of a golf club measured during the time that said golf club is not being used in a swing may thus be ignored.

As an example, in the simplest case in which N equals 1 and only one envelope section is calculated, a single motion signal envelope having a narrow beginning and a much wider end may be calculated from multiple motion signals, said motion signals starting out being substantially equal, e.g. having little variation, but varying wildly as time progresses. For constructing a motion signal envelope having an upper and a lower limit, motion measurements of at least two similar but different motions must be available, though preferably eight to ten motion measurements are obtained for calculating the envelopes. A plurality of example motions can be performed, of which only the best are included in the multiple motions used in the learning phase. Whether or not to include an example motion for use in the learning phase is preferably decided by an expert, e.g. a sports instructor or a physiotherapist.

According to the invention the method further comprises a subsequent comparison phase comprising the steps of:

- obtaining a further motion measurement over time, said further motion measurement comprising N further motion signals over time,

- determining, for said further motion measurement, a first anchor point representative of the first characteristic point in the corresponding further motion measurement,

- centering the first anchor point of the further motion measurement at the first common anchor point,

- generating a comparison signal indicating whether said further motion measurement falls outside one or more predetermined sections of the N envelopes or not.

During this phase, further motions, e.g. motions made once the learning phase has completed, are performed and compared with the one or more envelope sections that were calculated during the learning phase. A comparison signal is generated indicating whether said further motion falls within the envelopes, or predetermined sections thereof, or not. Thus the comparison signal indicates whether a further motion conforms to specifications learned in the learning phase. The first anchor point defines a first characteristic point or pattern in a motion measurement, allowing the comparison between an envelope and motion measurement to be made starting from said characteristic point or pattern, i.e. allowing offset correction between motion measurements and/or envelope sections. During the learning phase, a first anchor point is determined for each of said motion measurements for the purpose of calculating an envelope section from said multiple motion measurements. For instance, when an accelerometer attached to a golf club is used to provide a motion signal in the golf swing example, a first anchor point, in this case the time of impact, can be determined by detecting a deceleration due to impact with the ball, followed by an erratic motion signal caused by oscillation of the golf club directly after impact. Though motion measurements will be made prior to that point of impact as well, typically only measurements made within a limited predetermined time period prior to and/or after the moment of impact will be interesting to analyze. Such a predetermined time period is relative to the first anchor point and defines a predetermined section of an envelope. During the comparison phase irrelevant or superfluous measurements can be ignored by only comparing said motion measurements and envelopes within these predetermined sections, reducing memory and computational capacity requirements. Preferably a first anchor point of a motion measurement is determined based on a predetermined characteristic point or pattern of like motion measurements, i.e. the same characteristics may be used for determining the first anchor points during both the learning and the comparison phase, independent of the results of the learning phase. In this case the method would be especially suitable for analyzing motions having a known characteristic part in common, while requiring a relatively small number of motions to be repeated in the learning phase.

In an embodiment the method comprises a step of retrieving a predetermined characteristic point or pattern associated with a repeated motion from a database. The database is preferably accessible through an internet connection and comprises a large number of predetermined characteristic points or patterns for repeated motions in a wide range of applications. Examples of such applications are golf swing practice, wherein the characteristic point may be the point of impact of a club with a ball, revalidation therapy, wherein the motion sensors may be attached to for instance a knee brace and the characteristic point may be a point of impact of a foot on the floor, and industrial processes in which a motion is repeatedly executed, wherein the characteristic point may for instance be defined by a motionless moment followed by an acceleration. Each individual motion is preferably non-cyclic allowing anchor points to be determined non-ambiguously from the corresponding motion measurement.

Alternatively, the learning phase may comprise an additional step of determining such a characteristic point or pattern, for example by using a statistical method as known in the art for finding characteristics in multiple signals, or by using input from an expert during the learning phase. This would typically require a larger number of motions to be repeated during the learning phase.

In an embodiment the comparison phase comprises the additional steps of:

- counting a number C of consecutive of said further motion measurements for which predetermined ones of the N motion signals fall within the one or more predetermined sections of their corresponding envelopes, and storing said these motion measurements,

- updating one or more of said one or more sections of N envelopes based on the stored motion measurements when the number C exceeds a predetermined value.

The method thus provides a way to update the envelope sections when a certain desired consistency in the last C motion measurements has been found. In the golf swing example, when the predetermined value C should exceed equals ten, this means that the envelopes are updated when ten consecutive further motion measurements fall within the envelope sections. The predetermined value is a parameter which can be set in advance dependent on the application of the method, by a person performing the further motions, or by an expert. Entirely new envelopes may be calculated based on the last C motion measurements when these motion measurements were within the previous envelopes or sections thereof.

According to an embodiment the invention provides a method for adaptively converging individual envelopes dependent on the motion measurements obtained during the comparison phase, wherein envelope mean lines of successively updated envelopes may vary. Especially in sports, the best way to perform a motion varies from person to person. The present method provides a way to converge envelopes adaptively and subjectively, i.e. the envelopes will have different shapes and converge differently for different persons.

In an analogous embodiment, the envelope sections are updated when the last C motion measurements were outside the envelopes. The envelope boundaries may thus also be adaptively relaxed.

In an embodiment, the method comprises a step of updating the envelopes in dependence on time. In this embodiment the envelopes are for example relaxed as time progresses, to take into account gradual deterioration of sensors which provide the motion sensor signals, or of mechanical parts of a moving object to which such sensors are attached. This embodiment is especially advantageous for monitoring (partial) movement of mechanical devices used in industrial processes, e.g. for monitoring metering devices, drilling and/or cutting devices, placement devices and the like.

In an embodiment the method comprises the further steps of, during the learning phase:

- determining, for each of the multiple motion measurements, a second anchor point representative of a further characteristic point in the corresponding motion measurement different from the first characteristic point,

- normalizing the multiple motion measurements with respect to time, such that a common distance between the first anchor point and second anchor point is substantially equal for all motion measurements,

said method further comprising the steps of, during the comparison phase

- determining, for said further motion

measurement, a second anchor point representative of the second characteristic point in said further motion measurement,

- normalizing the further motion measurement with respect to time, such that a distance between its first anchor point and second anchor point is substantially equal to said common distance.

When two anchor points are thus obtained, the motion measurements are normalized with respect to time, making construction of the envelope less dependent on the tempo with which motions are performed. Likewise, fitting or curve-fitting of motion measurements, may be performed more accurately when more characteristic points are known.

In an embodiment the one or more predetermined sections of the one or more envelopes are defined relative to the first common anchor point. Referring to the example wherein the motion measurements are representative of a golf swing, such a golf swing can comprise several predetermined sections, such as for instance backswing, top of swing, downswing, impact and upswing. When it is known in advance that the first anchor point is defined by the moment of impact, and the timeframe of the downswing ranges from 2 seconds before impact to 1 second before impact, a section of a motion measurement comprising downswing motion signals can be identified as soon as the first anchor point has been determined.

In an embodiment each of the one or more sections of the N envelopes is a section of an envelope of overlain multiple motion signals from the multiple motion measurements. Each envelope section is thus formed by corresponding sections of a corresponding motion signal in a motion measurement.

In an embodiment the N motion signals are based on one or more motion sensor signals. For instance, a number of motion sensors, such as linear and/or rotational accelerometers, gyroscopes, and the like, can provide a corresponding number of motion sensor signals. When no further processing of the motion sensor signals is performed, the motion signals comprised in a motion measurement are equal to the motion sensor signals.

In an embodiment the method further comprises a step of calibrating the one or more motion sensors at the beginning of the learning phase, for instance in the following manner. First, the sensors are put at rest in a known position and orientation, such that the expected values of the corresponding motion sensor signal are known. Next the actual motion sensor signals are read out. The difference between the expected signals and the actual signals is then used to calibrate the sensors.

In an embodiment the number of motion sensor signals is greater than N, and the method comprises a step of redimensioning the motion sensor signals to N motion signals. This method takes advantage of the fact that multiple inaccurate motion sensor signals can be combined to form fewer but more accurate motion signals. For effecting this redimensioning a simple conversion matrix may be used, as may other methods known in the art.

In an embodiment the motion sensor signals are averaged and/or smoothed prior to further processing. This helps to cancel out the effect of noise in the motion sensor signals. The averaging and/or smoothing may also comprise reducing the number of samples in a motion sensor signal. For example, a motion sensor signal comprising 600 samples $n_i$ may be reduced to a motion sensor signal comprising 300 samples $n_i'$ using the formula: $n_i' = (n_{2i} + n_{2i+1}) / 2$, with *i* ranging from 0 to 300.

In an embodiment the upper and lower limits of the envelope at a time t are generated using a statistical method, such as least squares fitting, over a window around t. Thus an envelope may be generated having a relatively smooth upper and lower limit.

In an embodiment, for the purpose of determining a first or second anchor point of a motion measurement, only one motion signal of the N motion signals in a motion measurement is used. This one motion signal is preferably the motion signal of the N motion signals in which characteristic point or pattern may be determined the most accurately and/or easily. Usually, the sensor or sensors contributing to this motion signal be will relatively accurate compared to the sensors which contribute to other motion signals.

In an embodiment a section of an envelope is defined by a mean line and a function defining a variation along that line over time, and updating said section of an envelope comprises updating said function. This allows updating of the envelopes without having to store the previous further motion measurements. For example, the envelope could be narrowed down when a number of motion measurements has been within the envelopes with a certain predetermined consistency, or conversely, the envelope could be stretched when a number of motion measurements has fallen outside of the envelopes with a certain predetermined consistency. Moreover, this embodiment provides a fast and simple manner in which to calculate a distance measure of said further motion measurement to the mean line. Examples of suitable distance measures are Euclidian distance and Mahalanobis distance. Preferably, narrowing an envelope alters the motion signal range, but does not alter the time range of the envelope.

In an embodiment centering of the first anchor points comprises aligning said first anchor points in time. In other words, the time-offsets of the motion measurements are reduced or substantially completely removed.

The present invention further provides a device for capture and analysis of a repeated motion of an object to which said device is attached, said device comprising: motion measurement generating means adapted for generating motion measurements representative of motion of the object, each motion measurement comprising N synchronized motion signals over time, first anchor point determination means, adapted for determining a first anchor point in a motion measurement, a first memory for storing motion measurements, an envelope generator adapted for centering multiple motion measurements at a first common anchor point and generating one or more predetermined sections of N envelopes from multiple stored motion measurements and their associated first anchor points, a second memory for storing said one or more predetermined sections of said N envelopes as well as the first common anchor point, a comparison unit, adapted for generating a comparison signal dependent on a comparison of stored predetermined sections of said N envelopes with corresponding predetermined sections of corresponding motion signals from a further motion measurement, said comparison comprising centering the further motion measurement at the first common anchor point stored in the second memory and subsequently determining whether said motion measurement falls outside one or more stored predetermined sections of the envelopes. Such a device allows learning a range of motions and providing feedback based on the comparison signal.

In an embodiment the motion measurement generating means comprises one or more motion sensors, wherein motion signals of these one or more motion sensors obtained during a single motion of the object are comprised in a motion measurement. In an embodiment the anchor point determination means and/or the envelope generator comprise a processing unit loaded with software

Many areas of application are conceivable, for instance sports training such as golf swing practice, during which a trainer can demonstrate multiple movements for providing multiple motion measurements during the learning phase, or have a pupil execute a plurality of motions, the trainer subsequently selecting which of those movements to include in the multiple motion measurements for the learning phase. Once the learning phase is complete, the pupil can practice on his own. The same principle can be applied for revalidation purposes. For example a knee, ankle, wrist or elbow brace may be fitted with sensors for providing the motion signals, and a physiotherapist can supervise correct motions of a patient. Moreover, the present invention can also be applied in a broad range of industrial processes in which movement or partial movement of machines must be monitored to ensure these stay within tolerances.

In an embodiment the device further comprises an update-unit adapted for updating the predetermined sections of envelopes based on motion measurements stored in the first memory and information about their associated first anchor points, and based on whether a predetermined number of consecutive comparison signals have indicated that a corresponding number of consecutive motion measurements has either fallen within the predetermined sections of the envelopes or outside thereof. This allows automated updating of the envelopes during the comparison phase, at least when motion measurements made during the comparison phase are stored in the first memory. Thus, when further motions performed during the comparison phase are consistent yet not within the envelopes, updated envelopes may be calculated based on said motions. This will result in fewer motion measurements falling outside of the updated envelopes when the motion signals measured shortly after one another are substantially similar yet slow variations occur over time. In a similar manner, the update unit may provide updated envelopes or sections thereof defining a narrower range of motions when a consecutive number of motion measurements fell within the previous envelopes or sections thereof.

In an embodiment the device further comprises one or more motion sensors for providing motion sensor signals on which the motion measurements are based. Examples of such motion sensors are accelerometers, gyroscopes, position sensors and the like. Alternatively, other types of sensors may be used, such as humidity sensors, light sensors, pressure sensors, chemical concentration monitoring sensors, and so on, without deviating from the principle behind the present invention.

In an embodiment the device further comprises a calibration unit for calibrating said motion sensor signals, increasing the accuracy of the sensor readings.

In an embodiment the device is an integrated device and the one or more motion sensors are in a fixed position with respect to each other and the integrated device. Thus the resulting motion sensor signals represent the motion of the entire device and may more easily and accurately be combined or processed to describe the actual motion of the device.

In an embodiment the device is adapted to be mounted on the object, such as a golf club, preferably on the shaft of a golf club, more preferably detachably mounted thereon. In this embodiment a game of golf may be played with a conventional club to which the device is attached, and the same motion capture and analysis device may be used consecutively on different clubs.

In an embodiment the device further comprises feedback means for providing an audible, visual, and/or tactile feedback based on the comparison signal. The feedback means may comprise one or a combination of a number of LEDs, with each led indicating whether part of a motion was outside a corresponding section of one or more envelopes, a speaker for generating a sound, wherein the pitch of the sound is substantially different depending on the comparison, and or a vibrating unit, which is adapted to vibrate based on the comparison signal.

The various aspects and features described and shown in the specification can be applied, individually, wherever possible. These individual aspects, in particular the aspects and features described in the attached dependent claims, can be made subject of divisional patent applications.

## BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be elucidated on the basis of an exemplary embodiment shown in the attached drawings, in which:

Figure 1A shows an envelope representing a range of motion signals over time together with a mean envelope line,

Figures 1B and 1C show two motion measurements used in defining the upper- and lower limits of the envelope of figure 1A,

Figures 2A-2F show how an envelope is constructed from multiple motion measurements,

Figure 3A, shows three envelopes each representing a range of motion signals, as well as three corresponding motion signals of a further motion measurement,

Figures 3B and 3C show two of the envelopes and corresponding motion signals of figure 3A individually,

Figure 4A shows a schematic layout of components for obtaining motion measurements and generating a motion envelope, as used in a device for motion capture and analysis according to the present invention.

Figure 4B shows a schematic layout of components for obtaining motion measurements and comparing such motion measurements to a generated envelope.

Figure 4C shows a schematic layout of an embodiment of a device according to the present invention.

Figures 5A and 5B show schematic layouts of components for obtaining motion measurements and generation a corresponding envelope, and for obtaining motion measurements and comparing such motion measurements to a generated envelope, suitable for processing motion measurements comprising multiple motion signals.

Figures 6A-6D show a golf club to which a detachable device according to the present invention is attached, as well as the device in different clamping positions.

Figure 7 shows an alternative application of the device, in which it is placed on a knee-brace,

Figures 8A and 8B show a flow chart describing the method according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1A shows an envelope E calculated from multiple motion signals using the method or device according to the present invention. Envelope E defines an upper limit 102, and a lower limit 103 for the magnitude of motion signals along the vertical axis V. The magnitudes of upper and lower limits are measured by taking consecutive samples *n*, *n* in this case ranging from 0 to 750 as indicated on the horizontal axis. Motion signals may be obtained for instance using a linear accelerometer attached to a shaft of a golf club, and arranged for measuring acceleration parallel to said shaft. Any motion signal falling between the upper- and lower limits is within specifications of envelope E. The envelope has a mean line 101 which is equidistanced from the upper- and lower limits 102,103, i.e. mean line 101 bisects lines 104,105 along the vertical axis which connect the upper- and lower limits 102,103. A first anchor point t0 is representative of a first characteristic point or pattern common to individual motion signals associated with repeated motions, in this case defined by a somewhat erratic change in the signal just before a change in gradient of the signal. Typically, not all samples are relevant for evaluating the quality and/or consistency of a movement. For example, samples taken when a golf player is walking from one hole to the next will typically not be used in training a golf player's swing. In this figure, only samples within the range defined by section 106, i.e. samples 250 to 750, of the envelope are considered relevant. The relevant envelope section or sections are typically predetermined and defined relative to the first anchor point; once the anchor point t0 is known the relevant envelope sections can be determined and samples from the remaining section(s) of the motion signal may be discarded or ignored. Though only one envelope section is shown here, it is conceivable that an envelope comprises several of such predetermined envelope sections.

Figure 1B shows a motion signal 102 which contributed to defining said upper limit 102 of figure 1A. Though for reasons of clarity only one motion signal is shown, in general multiple motion signals will contribute to defining the upper- and lower limits. Consecutive samples *n* are plotted along the horizontal axis, and the vertical axis represents the magnitude of the signal. The motion signal comprises a first anchor point at t0 defined by the first characteristic point as described in figure 1A.

Figure 1C shows a motion signal which contributed to defining the lower limit 103 of the envelope E of figure 1A, said motion signal having its own anchor point at t0, in this case around sample no. 715. Again, for reasons of clarity only one motion signal is shown, though in general multiple motion signals will contribute to defining the upper- and lower limits. As sampling of the relevant section 106' of this motion signal started later, than of the signal in figure 1B, i.e. about at sample 350 instead of a about sample 250, the signal, though similar, is shifted to the right with regard to the signal of figure 1B. However, because the characteristic points for both motion signals are the same, these characteristic points can be centered at a common first anchor point as shown in figure 1A. Once this common anchor point is known, it is also possible to define a time axis for the motion signals and for the envelope, said time axis being calculated from the sampling frequency and number of samples and having its origin at common anchor point t0.

In figure 1A the envelope E was constructed using motion signals of only two motion measurements. However, it is often desirable to use more than two motion signals for generating, e.g. when the two motion signals intersect when plotted, and/or when the two motion signals much more similar to each other than other motion signals of motions repeated for instance during the learning phase.

Figures 2A-2F shows how an envelope E′ may be calculated form motion signals from multiple motion measurements, using the method or device according to the present invention. Figure 2A shows the envelope E′ in a graph in which the magnitude V of the upper limit 102 and lower limit 103 is plotted against a point in time t. As the upper- and lower limit 102,103 differ significantly in shape the envelope E′ is non-symmetrical. At time t0 a characteristic pattern occurs in each motion signal, which can be used for centering the multiple motion measurements. The envelope itself may not show the characteristic pattern, as the envelope is derived from multiple motion signals. The motion signals shown figures 2B-2F do show the characteristic pattern around time t0, the pattern being an erratic motion signal measured at the point of impact between the golf club and a golf ball, and being easily recognizable as the measured motion signal before and after the point of impact is relatively smooth. Because the motion signals are erratic around time t0, the envelope around that time t0 in the interval indicated by hatched portion 109 is not used. Alternatively the envelope may be made very wide such that the upper limit of the envelope around t0 is close to or equal to a maximum magnitude of a motion signal, and the lower limit of the envelope around t0 is close to or equal to a minimum magnitude of a motion signal. For the envelope E′ shown, when comparing a motion signal with the envelope E′, comparison takes place over the range of the envelope E′ defined by its relevant and predetermined sections 107,108 wherein section 107 defines the envelope for a time range of approximately 1 to 0.05 seconds before the time of impact t0 of the golf club with a ball, and wherein section 108 defines the envelope for a time range of approximately 0.05 to 0.4 seconds after this time of impact t0.

The upper limit 102 of envelope E′ is comprised of two parts derived from two motion signals of two separate motion measurements which are shown in figures 2B and 2C, wherein the first part defines the upper limit from time t1 to t2, and wherein the second part defines the upper limit from time t2 to t5. Figure 2B shows a plot of a motion signal M1 of a first motion measurement which is used to form part of the upper limit of envelope E. The motion signal M1 is erratic at the point of impact t0 of the golf club with a ball. Though a single motion signal from a single motion measurement is not sufficient to generate an envelope according to the present invention, the motion signal M1 of the first motion measurement initially defines both the upper limit 102b and lower limit 103b of the envelope E’. Preferably at least three or more motion measurements are made to generate an envelope. Figure 2C shows how the upper limit 102c1,102c2 and lower limit 103c1,103c2 are updated when a motion signal M2 of a second motion measurement is used. The dotted line shows the envelope as far as constructed using the motion signal M1 from the previous motion measurement. Part 102c1 of the upper limit between time t1 and time t2 is the same as the corresponding part of the upper limit 102b of figure 2B. However, beyond time t2 the magnitude of part 102c2 of the motion signal M2 of the second motion measurement is greater than the magnitude of the corresponding part 103c2 of the motion signal M1 of the first motion measurement, such that the upper limit of the envelope E’ is updated to comprise parts 102c1 and 102c2. Likewise, the lower limit 103c1, 103c2 is updated to comprise part 103c1 of motion signal M2 of the second motion measurement and part 103c2 of motion signal M1 of the first motion measurement.

In figure 2D a motion signal M3 of a third motion measurement is shown. As part 103d1 of this signal M3 has a lower magnitude than the lower limit of the envelope E’ constructed thus far, the lower limit is updated to comprise part 103d1, which ranges from time t1 to t5. The upper limit formed by parts 102c1, 102c2 remains the same. In figure 2E the lower limit is further updated with parts of fourth motion signal M4 so as to comprise part 103e1 ranging from time t1 to t3, and part 103e2, ranging from time t3 to t5. Figure 2F shows how the envelope E′ constructed thus far is updated with portion 103f2, which ranges from time t4 to t5, such that the resulting lower limit comprises part 103f1, ranging from time t1 to t4, and part 103f2, ranging from time t4 to t5. The envelope of figure 2A is thus defined by an upper limit comprising parts 102c1, 102c2 and a lower limit comprising parts 103f1 and 103f2.

Figure 3A shows three envelopes E1, E2, E3 with three corresponding further motion signals S1, S2, S3 forming a further motion measurement. The three further motion signals S1, S2, S3 are synchronized and were obtained while the envelopes E1, E2, E3 were already available. The samples of the further motion signals are derived from signals from separate sensors, in this case from three orthogonally arranged linear accelerometers. The further motion signals comprised in the further motion measurement range over the same period of time and have been sampled using the same number of samples. The horizontal axis has been converted to a time-axis having its origin at first anchor point t0. It can be seen that the relevant section of a motion or envelope starts about 1 second before the anchor point, i.e. before the time of impact of the golf club with a ball. The entire motion measurement comprising the three motion signals has been centered at common anchor point t0 which is derived from a motion signal from only one of the sensors, in this case from S1.

Figures 3B and 3C show motion signals S2, S3 from the motion measurement respectively, each with its corresponding envelope section E2, E3, centered at the common anchor point t0. The motion signals S2 and S3 were measured after the envelopes E2, E3 were calculated. Both motion signals S2 and S3 fall within their corresponding envelopes, meaning that the measured motion associated with the motion signals conform to the motion ranges defined earlier.

In figure 4A a schematic diagram is shown of a part of a device according to the present invention, said part comprising motion measurement generating means 301 for obtaining motion measurements and a processing unit 302 for generating an envelope from multiple motion measurements, as is done during the learning phase of the method according to the present invention. Motion measurement generating means 301 comprise a motion sensor S0 adapted for providing a motion sensor signal 310, in this case at a predetermined sampling rate of 200 Hz. The motion measurement generation means 301 further comprise a first memory MEM1 for storing motion measurements, each motion measurement comprising a motion sensor signal from the motion sensor. Preferably, memory MEM1 has sufficient capacity for storing a plurality of motion measurements 311, each comprising a motion signal ranging over a duration of time equal to the duration of a relevant part of the repeated motion. For instance, if the relevant part of a golf swing typically takes 1.4 seconds, a memory MEM1 having a capacity to store a plurality of motion measurements all having a duration of at least 1.4 seconds would suffice, at least when only one section of the motion measurement is relevant. Preferably, the motion measurement generating means is implemented as an field programmable gate array or integrated circuit programmed to generate an envelope as described above. From said plurality of motion measurements, a multitude of motion measurements may be selected and subsequently used in generating the envelope. Alternatively, memory MEM1 may have sufficient capacity for storing only one motion measurement.

The device further comprises a processing unit 302, comprising first anchor point determination means ANCH adapted for providing a signal 312 representative of a first anchor point detected in a motion measurement 311 stored in the first memory MEM1. The motion measurement 311 and the signal 312 representative of the first anchor point are input to an envelope generator EnvG, which is adapted for centering the motion measurement on a first common anchor point and for generating one or more predetermined sections of an envelope from the centered motion signal. A signal 313 comprising the predetermined sections of the envelope together with the first common anchor point is stored in a second memory MEM2. Preferably, the anchor point determination means are implemented as a field programmable gate array or integrated circuit, which preferably forms a single unit with the motion measurement generator means.

Figure 4B shows a part of the device adapted for obtaining further motion measurements and comparing said further motion measurements to a predetermined envelope section generated by the part described in figure 4A. A further motion measurement 311 obtained from motion measurement generating means 301 is input to first anchor point determination means ANCH, which is adapted for providing a signal representative of a first anchor point in the further motion measurement 311. The further motion measurement 311 and associated signal representative of its anchor point 313, together with corresponding envelope and common anchor point 313 as stored in MEM2, are then input to comparison unit CMP0. The comparison unit CMP0 is adapted for generating a comparison signal 314 based on a comparison of the further motion signal with an envelope stored in second memory MEM2. Comparison of the signals comprises centering the further motion measurement at the first common anchor point and determining whether the centered motion measurement falls outside one or more predetermined sections of the envelopes or not. Thus the comparison signal is indicative of the extent in which the further motion measurement falls within the envelope. Again, the comparison unit is preferably implemented as a field programmable gate array, or an integrated circuit, and preferably forms a single unit with the motion measurement generator means and/or the anchor point determination means.

The device is provided with feedback means FDB, adapted for providing an audible, visual or tactile feedback based on the comparison signal. Moreover, the device comprises an update unit UPD which is adapted for keeping track of a consecutive number of comparison signals which indicate that a further motion measurement falls with predetermined sections of the envelope, and causes said consecutive further motion measurements to be stored in the first memory MEM1 (not shown). When a predetermined number of consecutive signals has fallen within the predetermined sections of the envelope, new and/or updated envelope sections are calculated in the manner described above, based on the stored consecutive motion measurements. The update is preferably carried out by replacing an earlier motion measurement stored in first memory MEM1 with a further motion measurement, and then recalculating the envelope based on the motion measurements stored in first memory MEM1. In an embodiment, this is done in a first-in-first-out manner, i.e. the oldest motion measurement in first memory MEM1 is replaced by a further motion measurement. In an alternative embodiment, the motion measurement to be replaced is selected out of all motion measurements stored in first memory MEM1 based on a distance measure between the upper or lower limit and the motion measurement. In this latter case, the motion measurement to be replaced would be the motion measurement closest to either the upper limit or the lower limit. Figure 4C shows a schematic diagram of a device for motion capture and analysis according to the invention, comprising measurement generating means 301 arranged for providing motion measurements to processing unit 302 and/or to comparator circuit 303, depending on whether the device has been switched to the learning phase or to the comparison phase. The device preferably comprises an integrated package, with the sensors being fixedly arranged relative to one another.

Figure 5A shows part of a further embodiment of a device according to the present invention, said part being adapted for obtaining motion measurements comprising multiple motion signals, and generating envelopes or envelope sections from multiple motion measurements. Multiple sensors S1,…,S5 are adapted for providing corresponding motion sensor signals 310a,…,310b, for instance whenever the sensors are moved. In the figure shown, the multiple sensors comprise three orthogonally arranged linear acceleration sensors as well as two angular acceleration sensors. The motion sensor signals are redimensioned by redimensioning unit REDIM, which is adapted for providing a motion measurement 311 having a number of motion signals 311a, 311b, 311c that is less than or equal to the number of sensor motion signals. Such redimensioning is typically implemented by multiplying the motion sensor signals with a redimensioning matrix, and is useful, for instance, when noise in separate motion sensor signals is likely to cancel out. Moreover, redimensioning or combination of signals may be used to convert motion sensor signals to more useful signals; for instance three signals from three separate linear accelerometers may be converted and/or redimensioned into two signals representing linear acceleration, and one signal representing angular acceleration. The redimensioned motion measurements are stored in first memory MEM1. First anchor point determination unit ANCH is adapted providing a signal 312 representative of an anchor point of a motion measurement stored in first memory MEM1. This signal 312 is input to three different envelope generators Env1,…, Env3, which are adapted for centering the redimensioned motion signals 311a,311b,311c comprised in the motion measurements at a first common anchor point and for generating corresponding envelopes or predetermined sections thereof from said motion signals. The phrase "predetermined" is to be taken to mean that the range along the horizontal axis, e.g. the time axis, is predetermined. The upper- and lower limits of an envelope section need not be predetermined. Second memory MEM2 is adapted for storing a common anchor point 315 of the envelopes 313a,313b,313c together with the individual envelopes or sections thereof.

Figure 5B shows a part of the device adapted for obtaining motion measurements and comparing said motion measurements to predetermined envelope sections, as generated for instance by processing unit 402. A motion measurement 311 obtained from motion measurement generating means 401 is input to first anchor point determination means ANCH. Said anchor point is preferably determined from a single motion signal of the motion measurement. Analogous to comparison unit CMP0 of figure 4B, comparison units CMP1, CMP2, CMP3 are adapted for generating a comparison signal 314 based on a comparison of the centered motion signals 311a,311b,311c with their corresponding one or more envelope sections stored in second memory MEM2. Feedback means FDB are adapted to provide an audible, visual or tactile feedback based on the comparison signal 314. Update unit UPD keeps track of the consecutive number of comparison signals 314 which indicate that a motion measurement falls with predetermined sections of the envelopes, and stores said consecutive motion measurements in the first memory MEM1 (not shown).

When a predetermined number of consecutive signals has fallen within the predetermined envelope sections, new and/or updated envelope sections are calculated in the manner described above, based on the stored consecutive motion measurements.

Figure 6A shows a golf club 500, comprising a handle 501, a shaft 502 and a club head 503. A device 510 for motion capture and analysis according to the present invention is attached to the shaft 502 just below the handle 501. The device 510 comprises three linear accelerometers, said accelerometers being adapted for measuring acceleration in orthogonal directions, and one of the accelerometers being oriented parallel to the shaft. The device comprises a display 511 for indicating the extent to which a further motion of the golf club conforms to earlier calculated and stored envelopes.

Figures 6B and 6C show the device of figure 6A in different clamping positions as it is clamped around a shaft of a golf club. The device may be easily attached to or detached from a golf club, allowing a golf player to use the same club during practice and competition play with and without the device attached respectively. In figure 6B it can be seen that the device is provided with an interface 513, in this case a USB interface. The interface 513 is accessible when the device is not clamped around the shaft of the golf club, and allows connection with a computer for exchange of motion measurement data. Additionally, the interface can be used to upload characteristic points or patterns for determining anchor point to the device. Such characteristic points or patterns are preferably stored in a database which is accessible through the internet. Though a USB interface is shown, it will be appreciated that any interface may be provided anywhere on the device, either wired or wireless.

Figure 6D shows exemplary feedback means 512 of the device. The feedback means comprises 8 LEDs, each LED adapted for indicating whether a further motion measurement was within a corresponding predetermined envelope section. This provides a golf player with information on different parts of his swing.

Figure 7 shows an alternative application of the device, in which it is placed on a knee-brace 610. The device comprises three accelerometers S1,S3, S4 for measuring acceleration of the device, and a potentiometer S2 for measuring an angle made at the joint. In this embodiment the position of sensors S1,…,S4 is not completely fixed relative to one another, though the sensor signal of S2 can provide an estimate of the relative positions of the sensors. The signals from the sensors are input to logic section 620, where the signals are processed in accordance to the present invention. Using such a brace, a physiotherapist can demonstrate a correct movement a couple of times to a patient. When at home the patient may practice and be provided with audible feedback through a miniature speaker in the device (not shown). Additionally, the device may be provided with an interface to a computer, allowing further motion measurements to be transmitted to the physiotherapist for analysis, and allowing updated envelopes or sections thereof to be transmitted back to the knee-brace after said analysis.

Figure 8A shows a flow chart describing an embodiment of the method according to the invention. The learning phase of the method starts at 710, after which a motion is performed with an object in step 711. A motion measurement is obtained in step 712, said motion measurement comprising N motion signals over time based on signals from motion sensors attached to the object. A first anchor point is determined in step 713, after which the motion measurement is centered at a first common anchor point. When previous motion measurements have been obtained the first common anchor point will already be known. In case no motion measurements had been obtained earlier during the learning phase, the first anchor point of the motion signal is defined as the first common anchor point.

Steps 711 through 714 are repeated to obtain multiple motion measurement. Finally, in step 715 one or more predetermined sections of envelopes defining ranges for the corresponding N motion signals are calculated from the multiple motion measurements.

In figure 8B the comparison phase of an embodiment of the method according to the invention is shown. After starting 720 the comparison phase, a further motion measurement is obtained 721, and its first anchor point representative of a characteristic point or pattern of the further motion measurement is determined in step 722. In step 723 the first anchor point of the further motion measurement is centered at the first common anchor point. Finally, a comparison signal is generated in step 724, indicating whether the further motion measurement falls outside one or more predetermined sections of the N envelopes or not.

In summary, the present invention relates to a device and method for motion capture and analysis of motion of an object, in which an adaptive envelope derived from multiple motion measurements is used for determining the extent to which a further motion measurement conforms to an envelope or section thereof derived from the earlier multiple motion measurements. The invention further provides a method for adaptively converging the envelope towards a non-predetermined envelope in dependence on a number of consecutive motion measurements made with the object, thus allowing subjective or tailor made improvement and/or monitoring of further motions.

It is to be understood that the above description is included to illustrate the operation of the preferred embodiments and is not meant to limit the scope of the invention. From the above discussion, many variations will be apparent to one skilled in the art that would yet be encompassed by the spirit and scope of the present invention.

# CLAIMS

1. Device for capture and analysis of a repeated motion of an object to which said device is attached, said device comprising:

motion measurement generating means adapted for generating motion measurements representative of a motion of the object, each motion measurement comprising N synchronized motion signals over time,

first anchor point determination means, adapted for determining a first anchor point in the motion measurement,

a first memory for storing motion measurements,

an envelope generator adapted for centering multiple motion measurements at a first common anchor point and generating one or more predetermined sections of N envelopes from multiple stored motion measurements and their associated first anchor points,

a second memory for storing said one or more predetermined sections of said N envelopes as well as the first common anchor point,

a comparison unit, adapted for generating a comparison signal dependent on a comparison of stored predetermined sections of said N envelopes with corresponding predetermined sections of corresponding motion signals from a further motion measurement, said comparison comprising centering the further motion measurement at the first common anchor point stored in the second memory and subsequently determining whether said motion measurement falls outside one or more stored predetermined sections of the envelopes.

2. Device according to claim 1, further comprising an update-unit adapted for updating the predetermined sections of envelopes based on motion measurements stored in the first memory means and information about their associated first anchor points, and based on whether a

predetermined number of consecutive comparison signals have indicated that a corresponding number of consecutive motion measurements has either fallen within the predetermined sections of the envelopes or outside thereof.

3. Device according to claim 1 or claim 2, further comprising one or more motion sensors for providing motion sensor signals on which the motion measurements are based.

4. Device according to claim 3, further comprising a calibration unit for calibrating said motion sensor signals.

5. Device according to any one of the claims 1-4, wherein the device is an integrated device and the one or more motion sensors are arranged in a fixed position with respect to each other and the integrated device.

6. Device according to any one of the claims 1-5, wherein the device is adapted to be mounted on a golf club, preferably on the shaft of a golf club.

7. Device according to any one of the claims 1-6, further comprising feedback means for providing an audible, visual, and/or tactile feedback of the comparison signal.

8. Method for capture and analysis of a repeated motion of an object, comprising a learning phase comprising the steps of:

- repeatedly performing a motion with said object,

- obtaining multiple corresponding motion measurements, each motion measurement comprising N motion signals over time based on signals from motion sensors attached to said object,

- determining, for each of the multiple motion measurements, a first anchor point representative of a first characteristic point in the corresponding motion measurement,

- centering the respective first anchor points of the multiple motion measurements at a first common anchor point,

- calculating, from the multiple centered motion measurements, one or more predetermined sections of N envelopes defining ranges for the corresponding N motion signals,

said method further comprising a comparison phase comprising the steps of:

- obtaining a further motion measurement over time, said further motion measurement comprising N further motion signals over time,

- determining, for said further motion measurement, the first anchor point representative of the first characteristic point in the corresponding further motion measurement,

- centering the first anchor point of the further motion measurement at the first common anchor point,

- generating a comparison signal indicating whether said further motion measurement falls outside one of the one or more predetermined sections of the N envelopes or not.

9. Method according to claim 8, wherein the comparison phase comprises the additional steps of:

- counting a number C of consecutive of said further motion measurements for which predetermined ones of the N motion signals fall within the one or more predetermined sections of their corresponding envelopes, and storing these motion measurements,

- updating one or more of said one or more sections of N envelopes based on the stored motion measurements when the number C exceeds a predetermined value.

10. Method according to claim 8 or claim 9, comprising the further steps of, during the learning phase:

- determining, for each of the multiple motion measurements, a second anchor point representative of a further characteristic point in the corresponding motion measurement different from the first characteristic point,

- normalizing the multiple motion measurements with respect to time, such that a common distance between the first anchor point and second anchor point is substantially equal for all motion measurements,

said method further comprising the steps of, during the comparison phase:

- determining, for said further motion measurement, a second anchor point representative of the second characteristic point in said further motion measurement,

- normalizing the further motion measurement with respect to time, such that a distance between its first anchor point and second anchor point is substantially equal to said common distance.

11. Method according to any one of the claims 8-10, wherein the one or more predetermined sections of the one or more envelopes are defined relative to the first common anchor point.

12. Method according to any one of the claims, 8-11 wherein each of the one or more sections of the N envelopes is a section of an envelope of overlain multiple motion signals from the multiple motion measurements.

13. Method according to any one of the claims 8-12 wherein the N motion signals are based on one or more motion sensor signals.

14. Method according to claim 13, wherein the method further comprises a step of calibrating the one or more motion sensors at the beginning of the learning phase.

15. Method according to claim 13 or claim 14, wherein the number of motion sensor signals is greater than N, and wherein the method comprises a step of redimensioning the motion sensor signals to N motion signals.

16. Method according to any one of the claims 8-15, wherein, for the purpose of determining a first anchor point of a motion measurement, only one motion signal of the N motion signals in a motion measurement is used.

17. Method according to claim 16, wherein a section of an envelope is defined by a mean line and a function defining a variation along that line over time, and updating said section of an envelope comprises updating said

function.

18. Method according to any one of the claims 8-17, wherein centering of the first anchor points comprises aligning of said first anchor points in time.

19. Method according to any one of the claims 8-18, comprising the step, of adaptively converging individual envelopes dependent on the motion measurements obtained during the comparison phase, such that envelope mean lines of successively updated envelopes may vary.

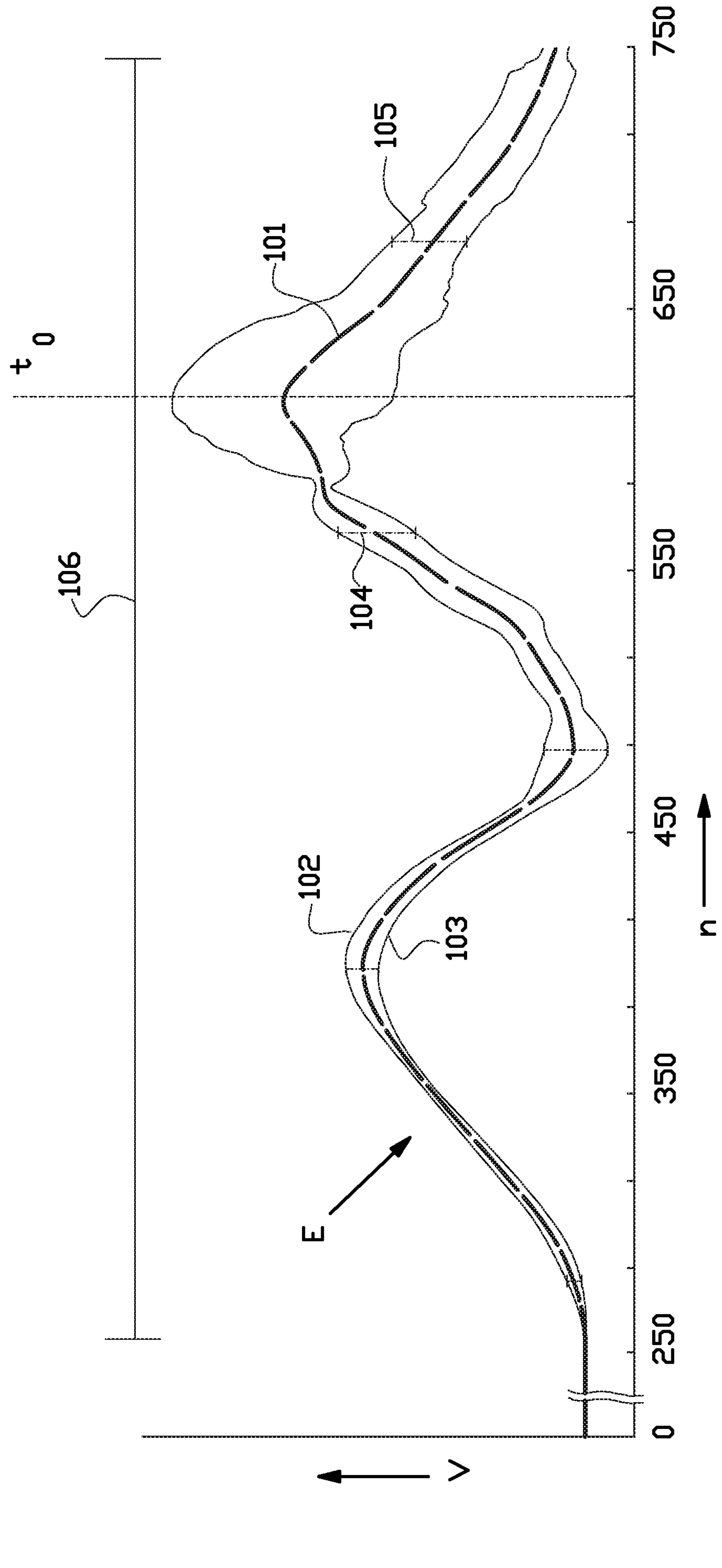


FIG. 1A

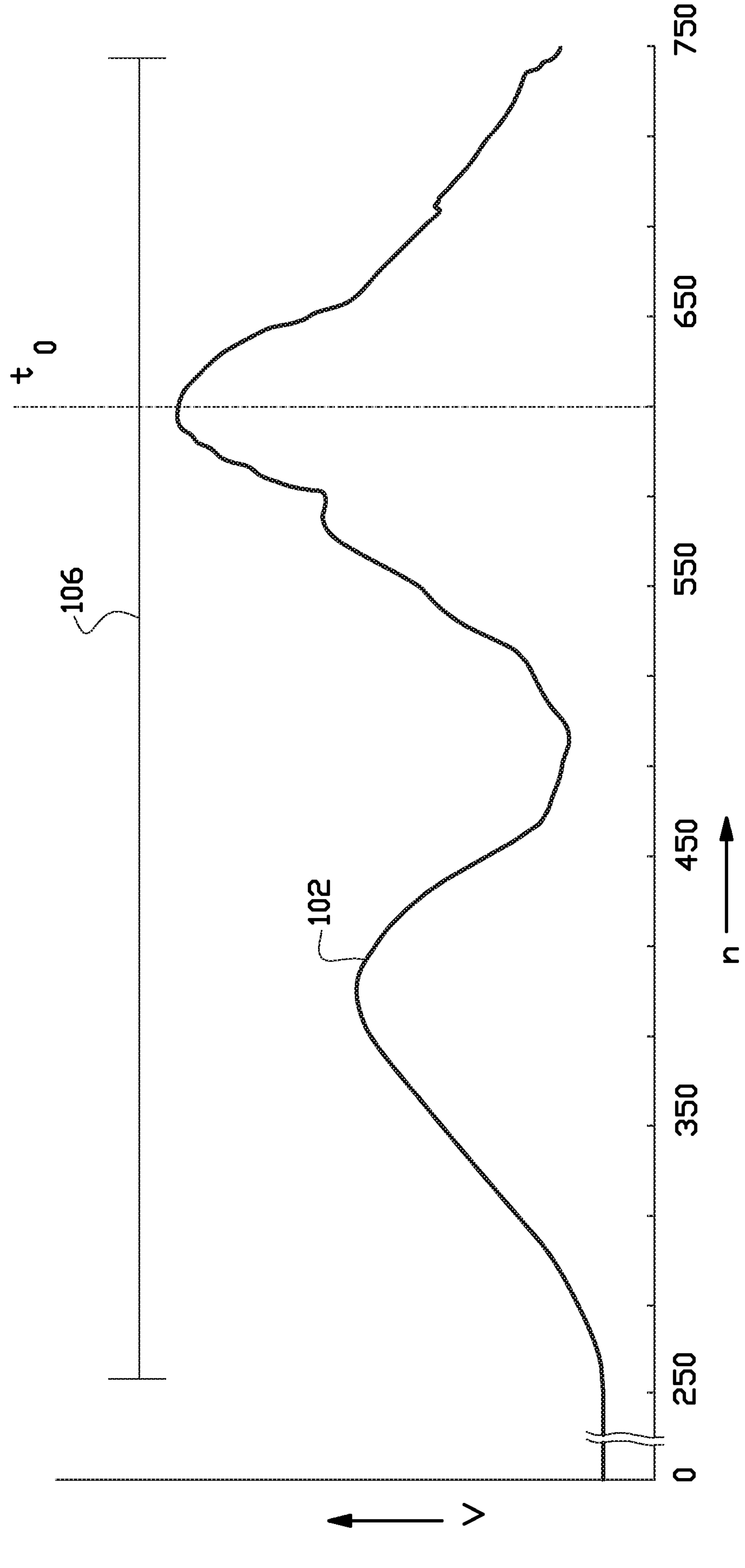


FIG. 1B

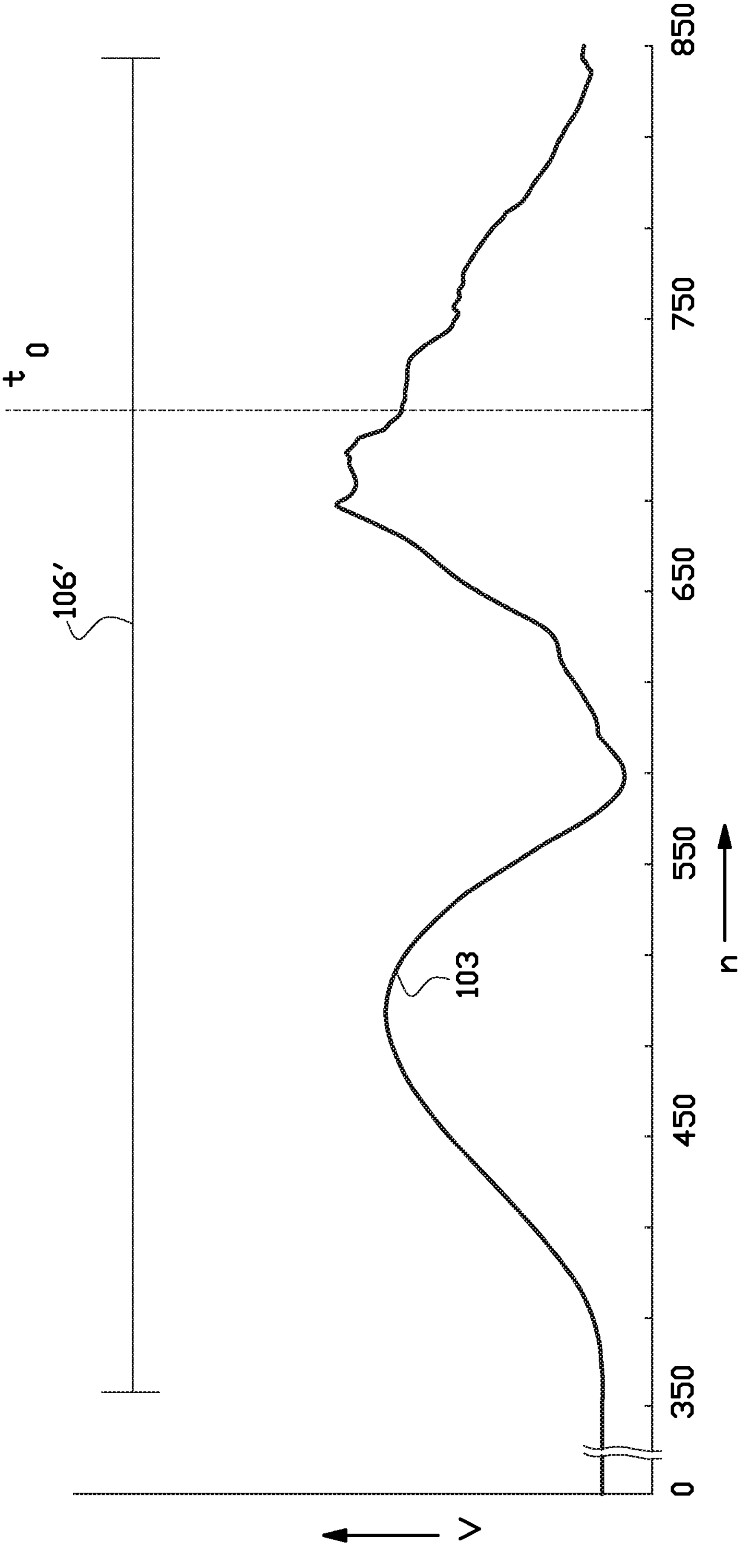


FIG. 1C

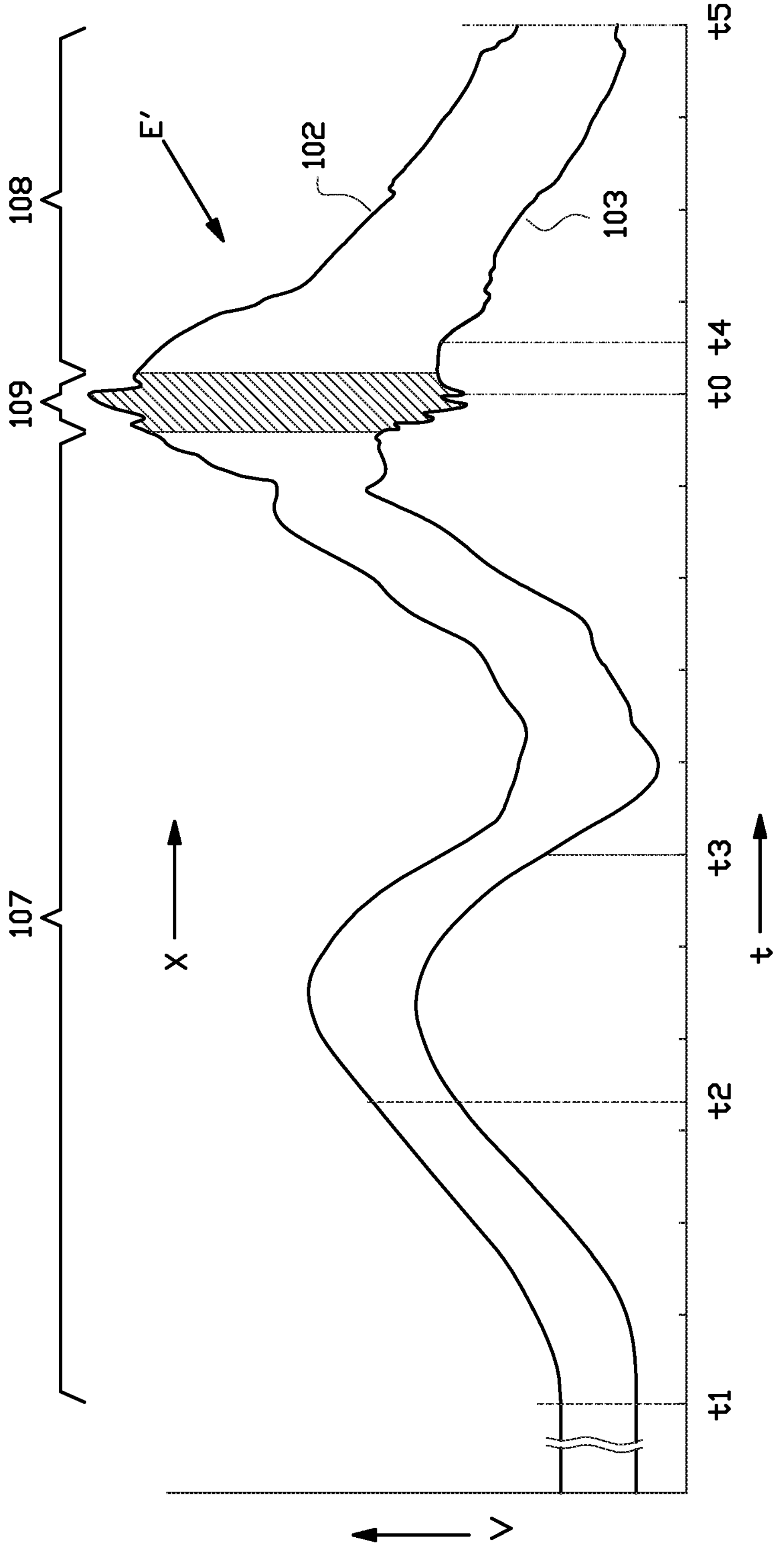


FIG. 2A

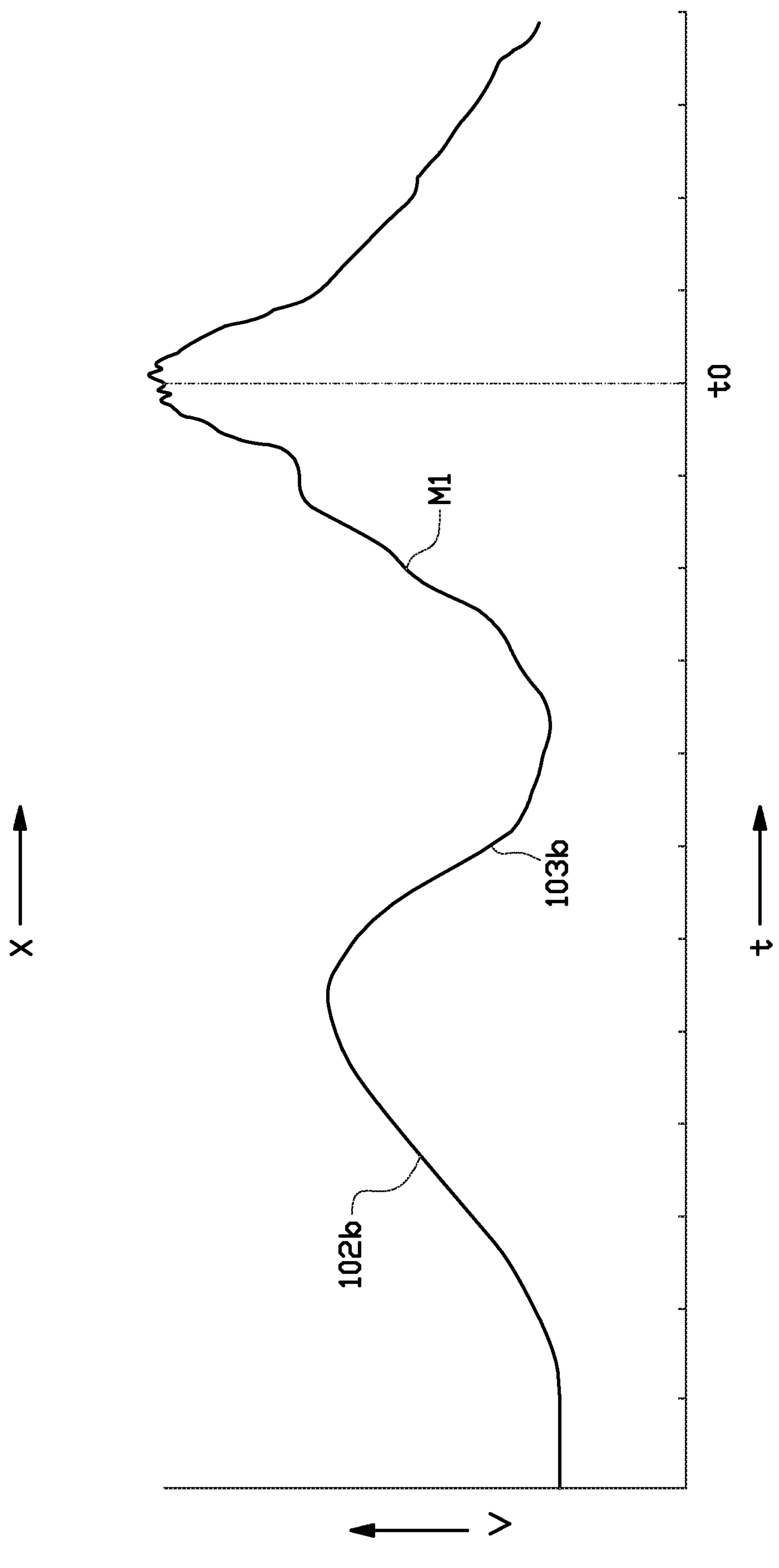


FIG. 2B

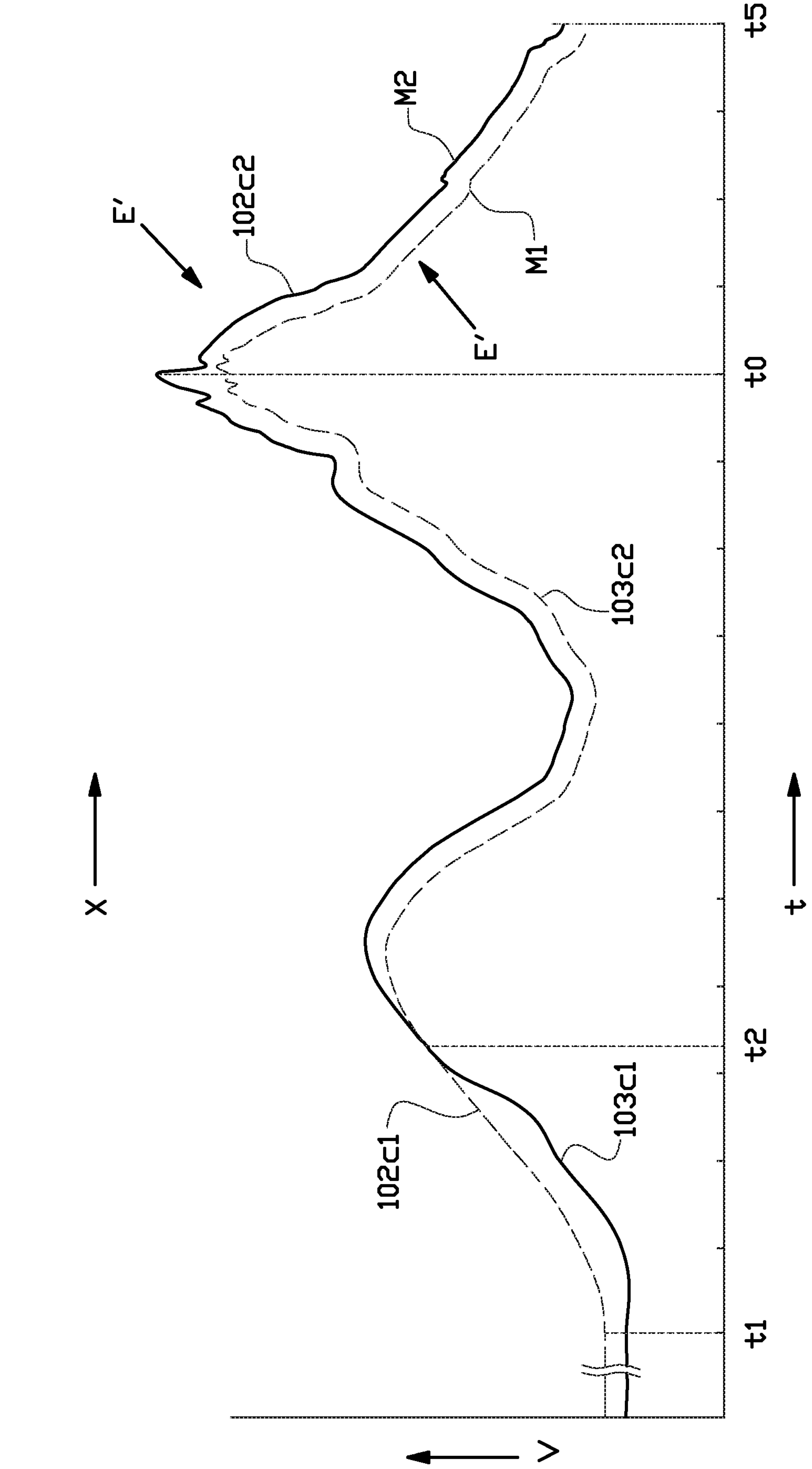


FIG. 2C

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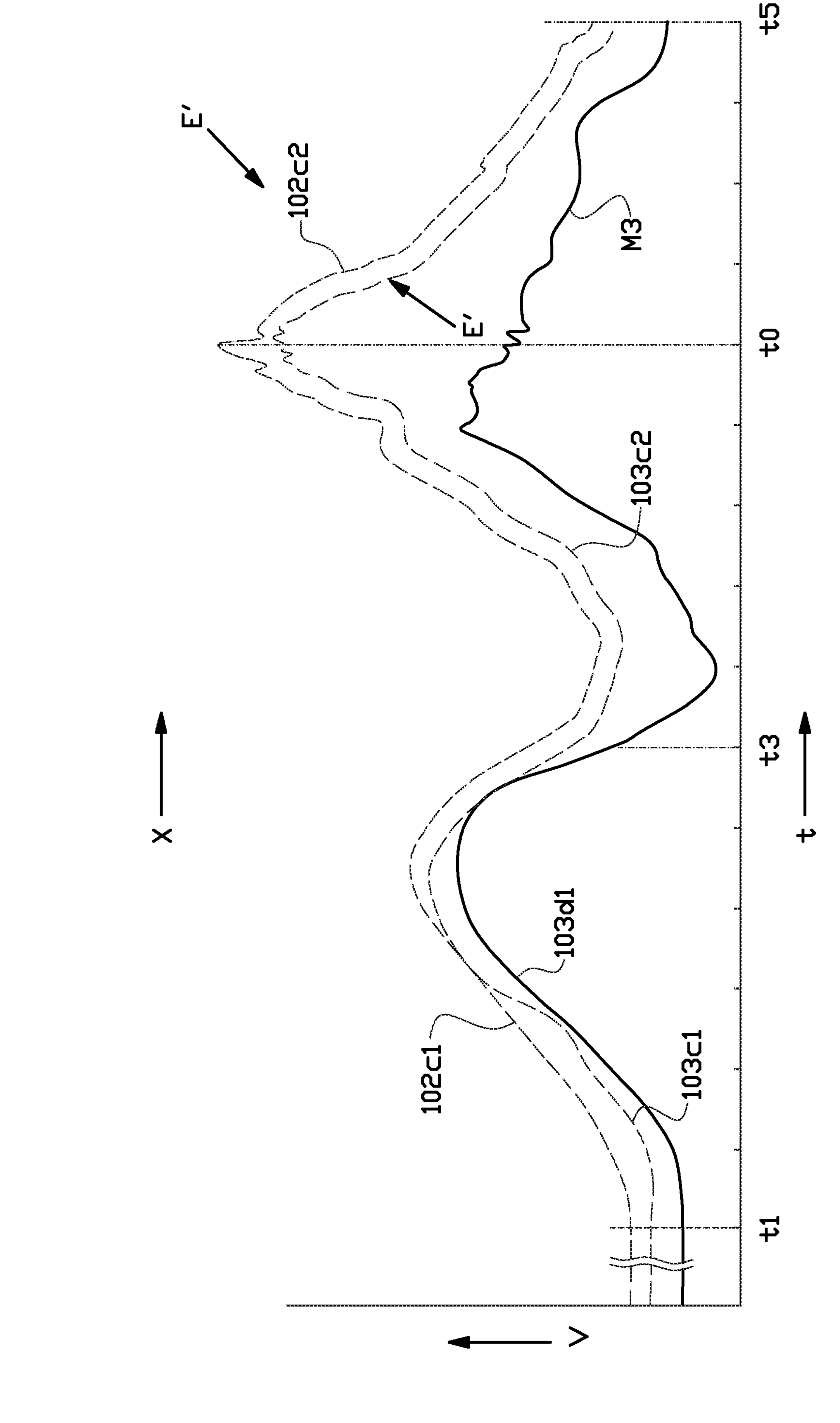


FIG. 2D

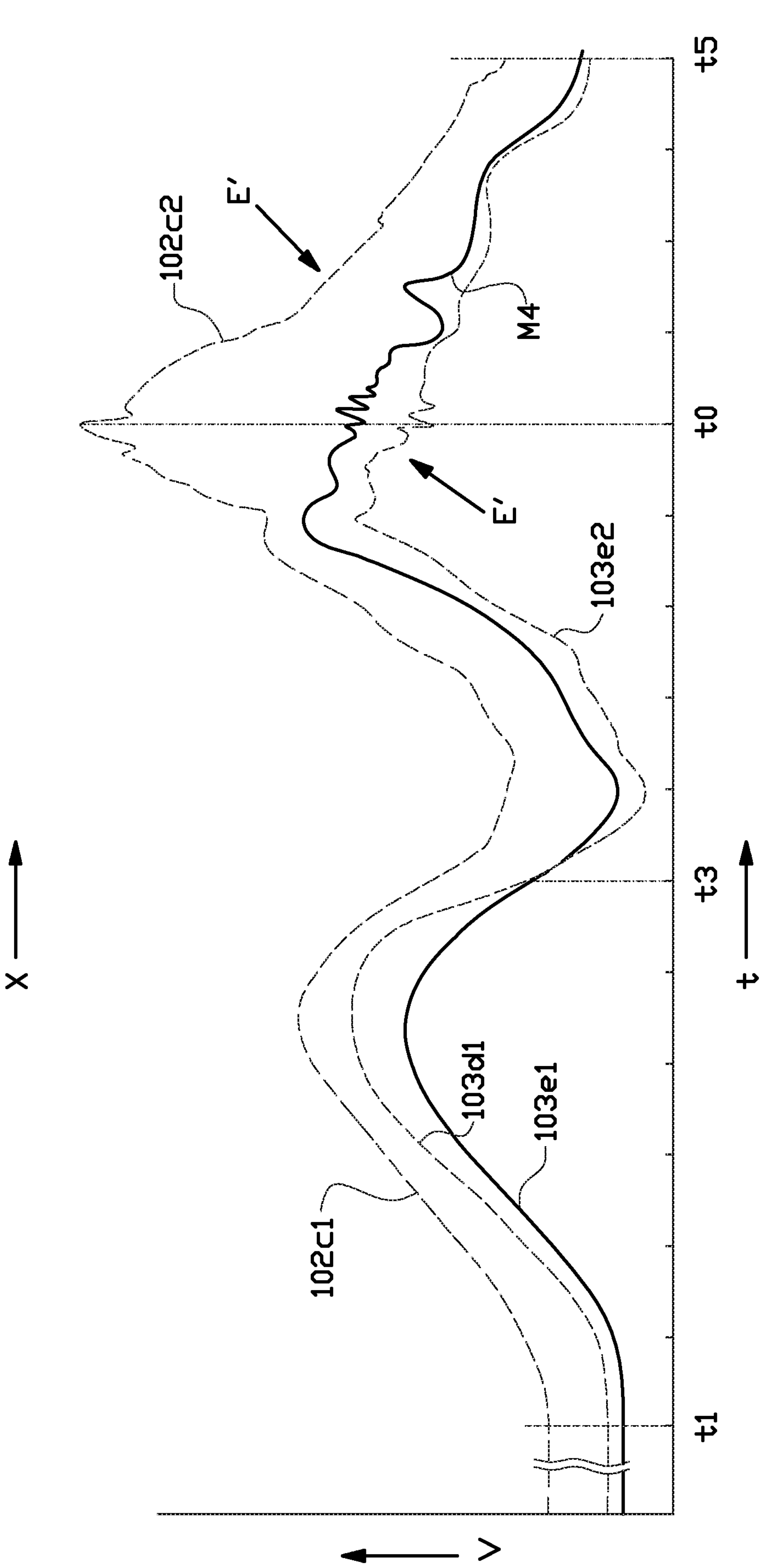


FIG. 2E

9/20

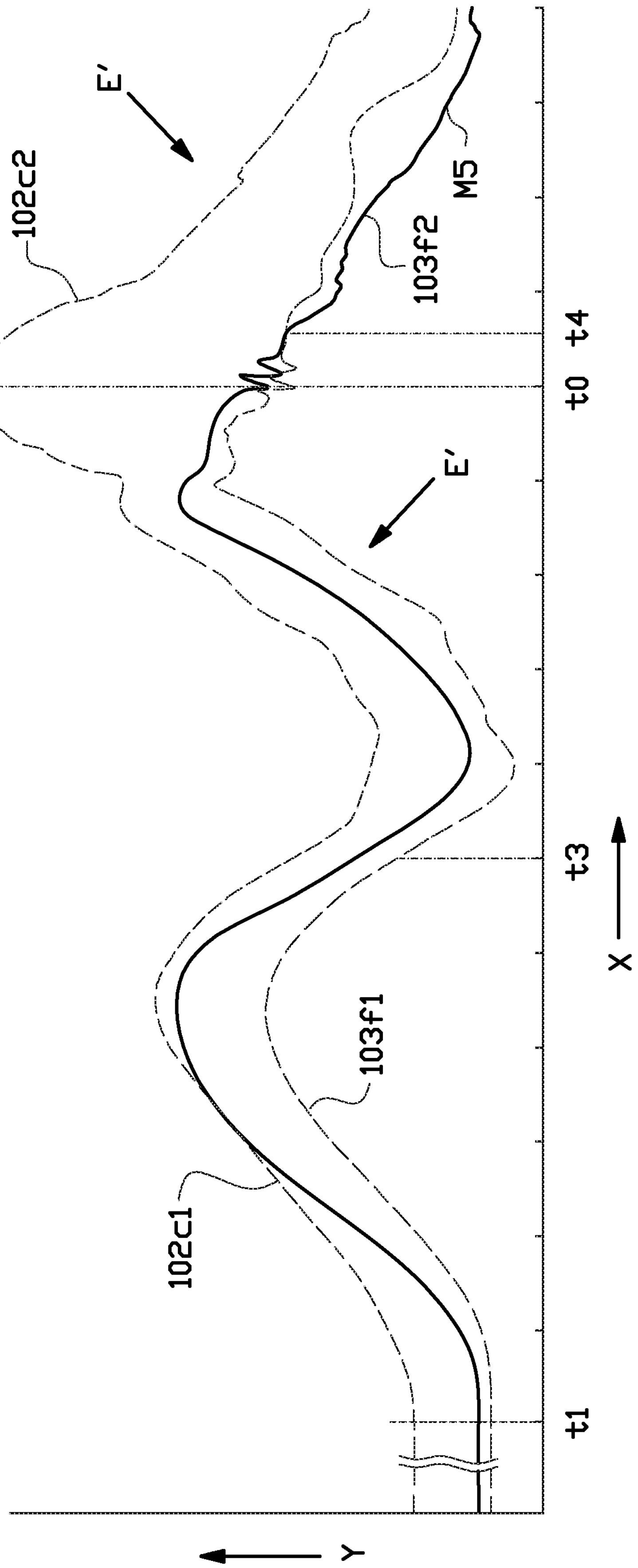


FIG. 2F

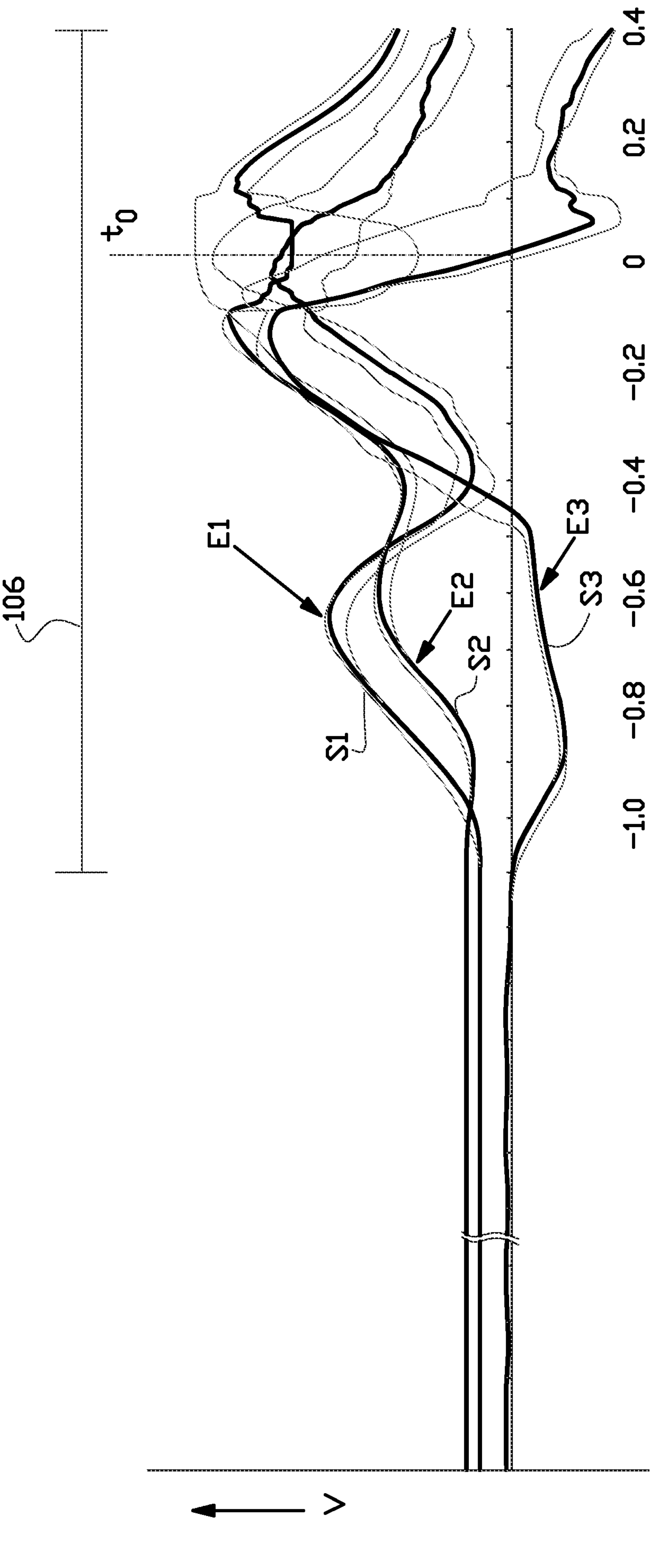


FIG. 3A

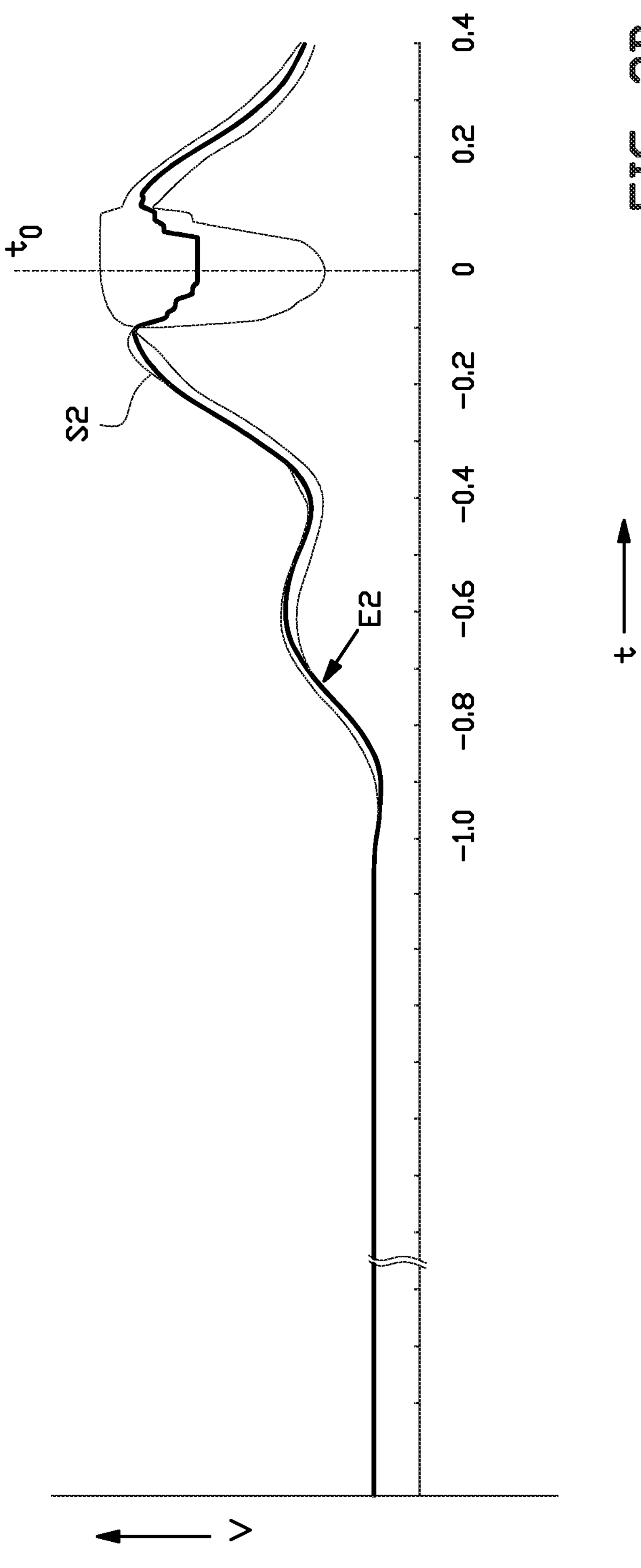


FIG. 3B

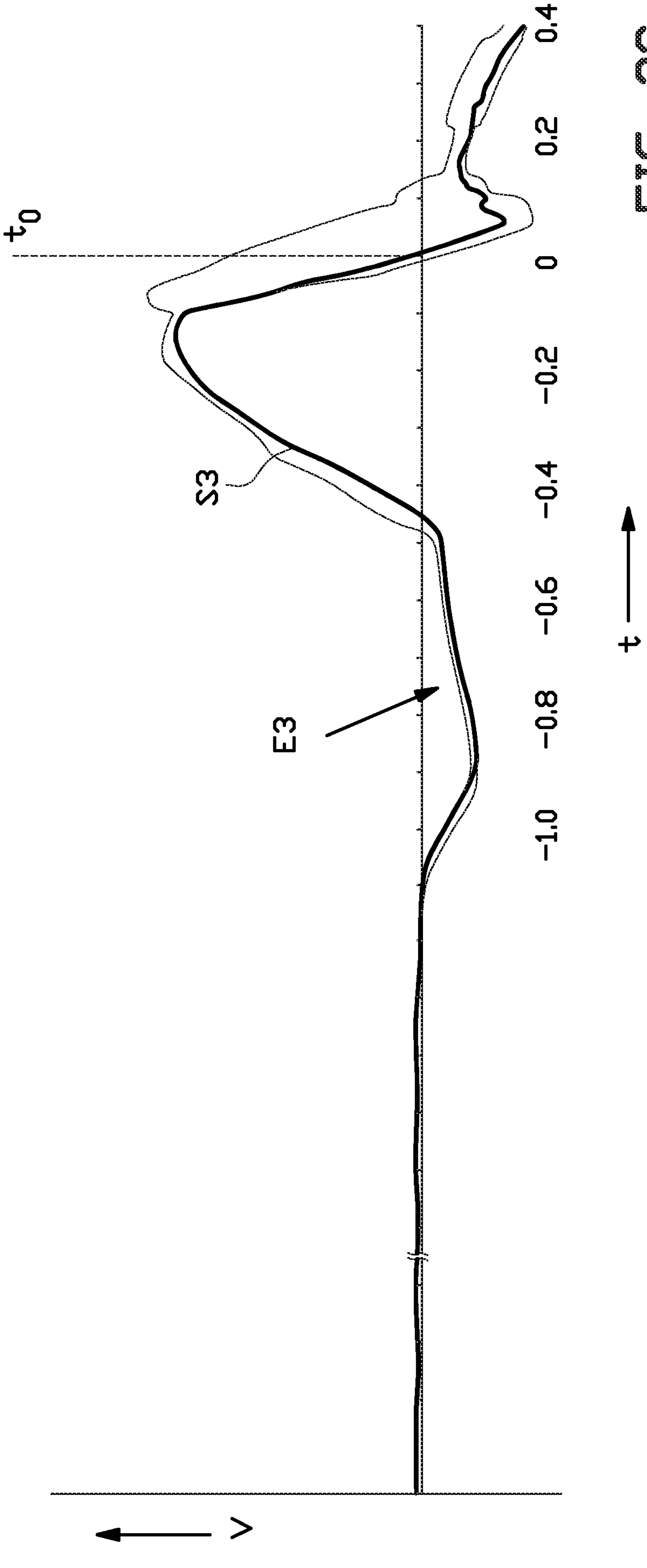


FIG. 3C

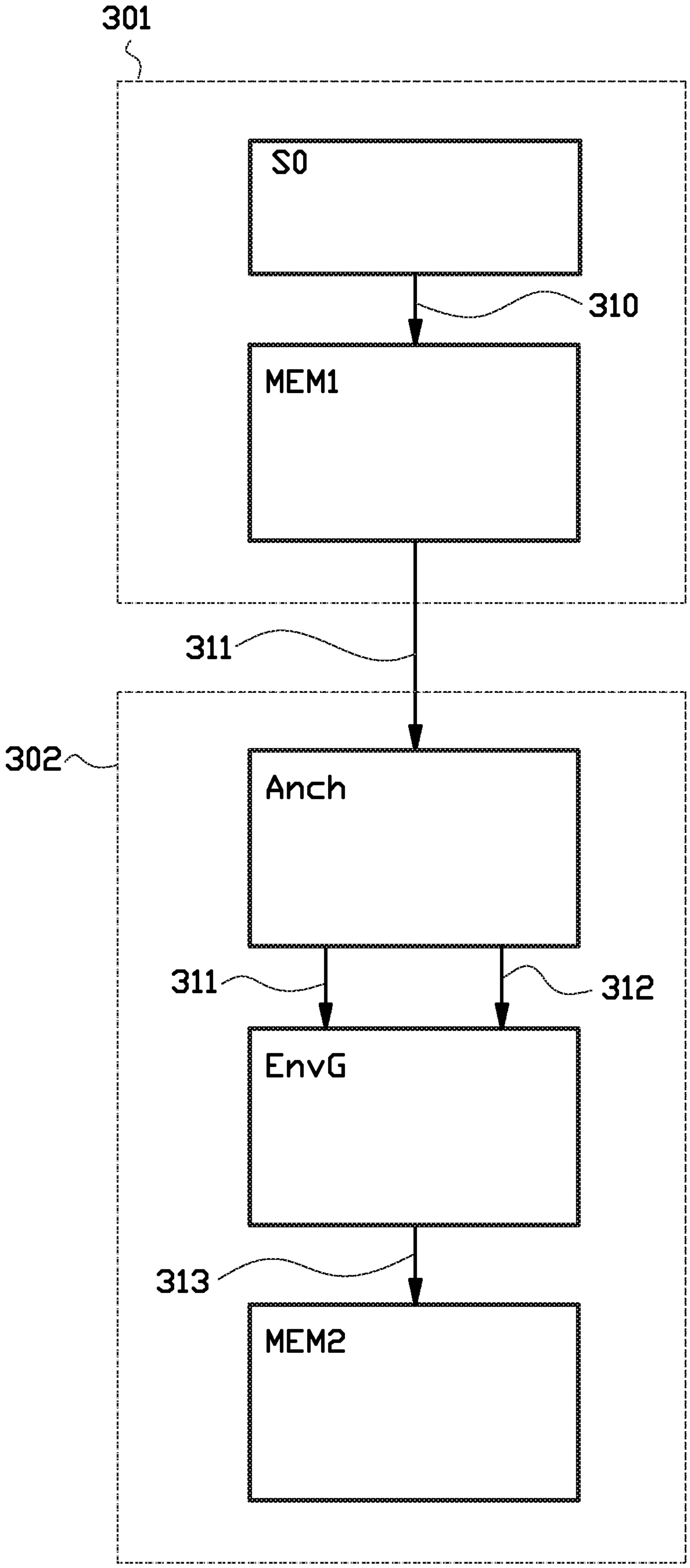


FIG. 4A

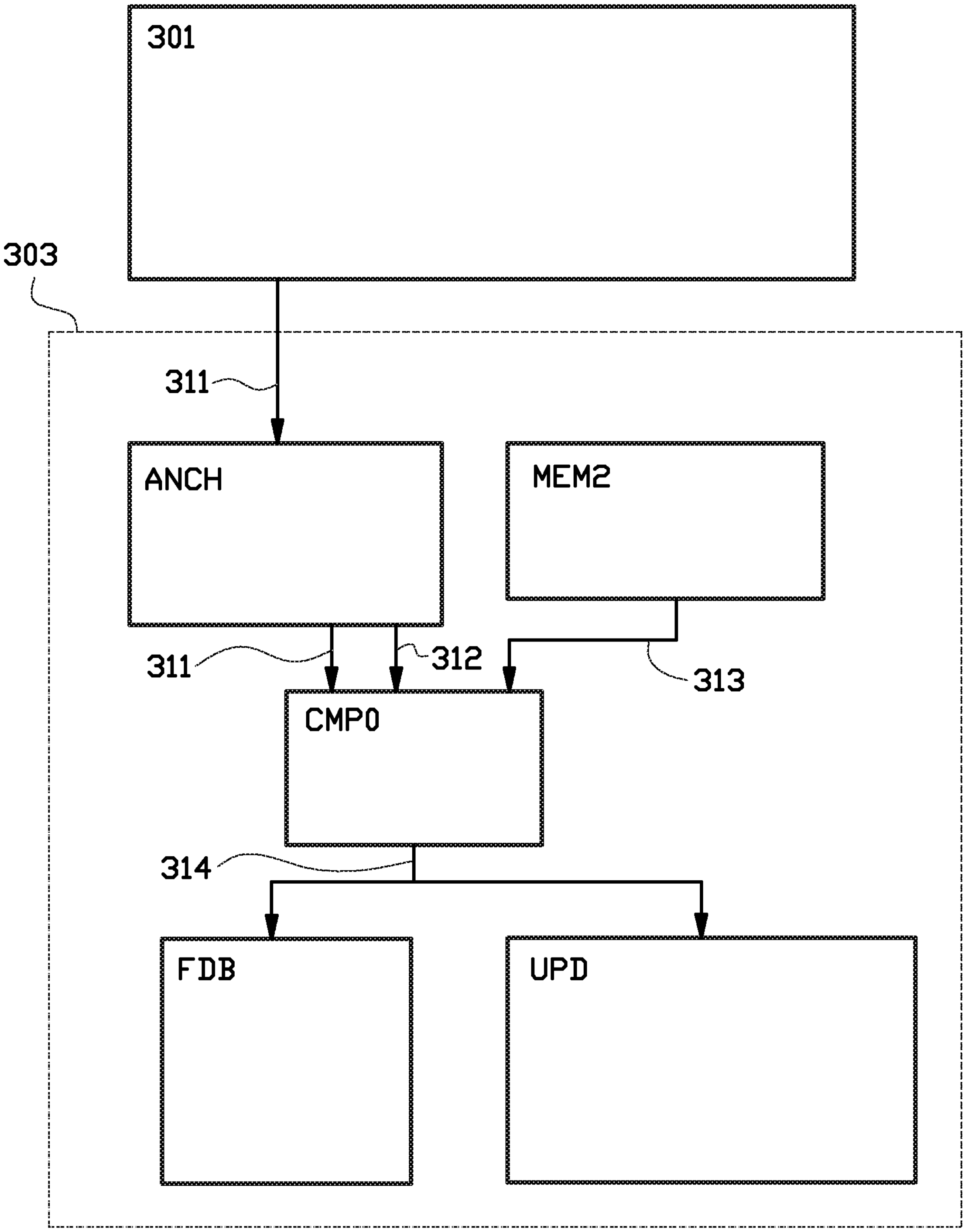


FIG. 4B

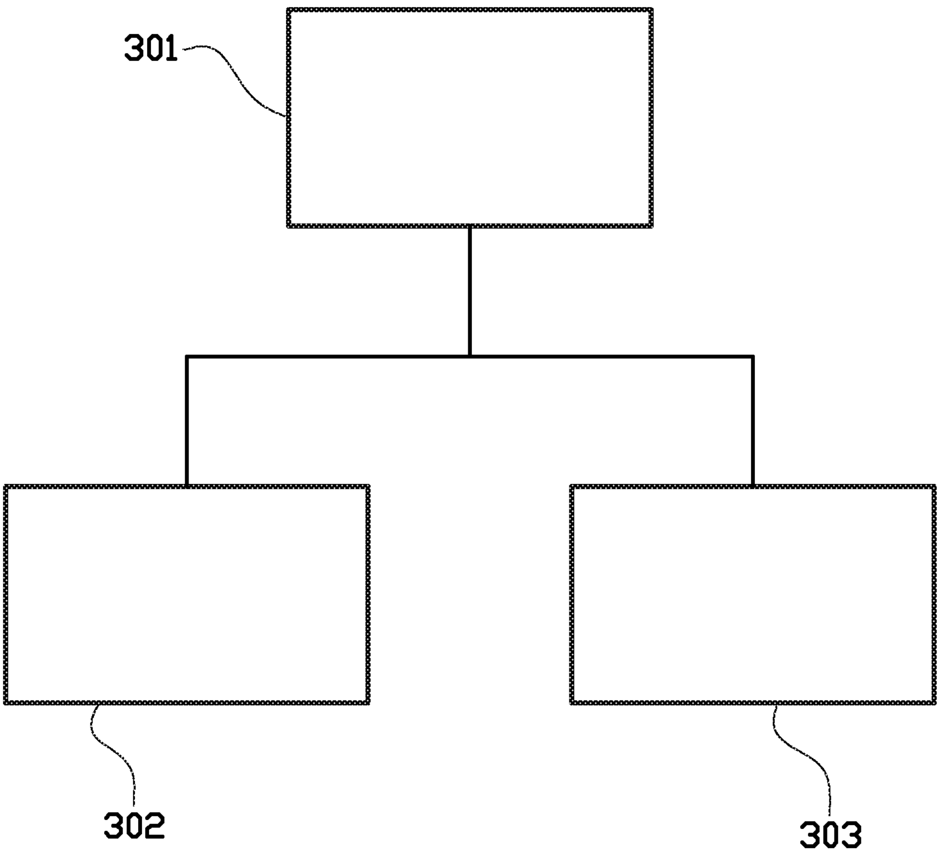


FIG. 4C

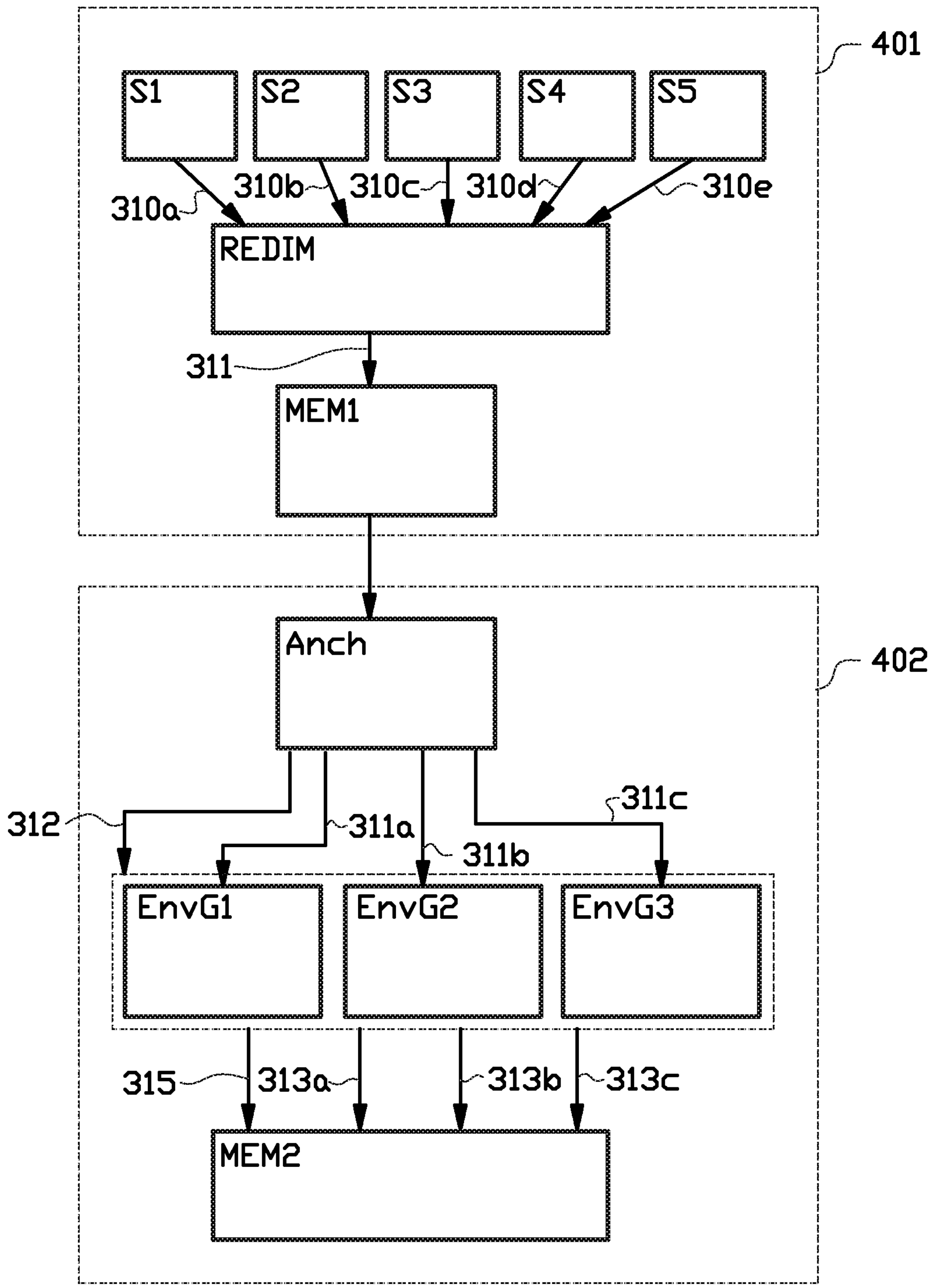
401
S1
S2
S3
S4
S5
310a
310b
310c
310d
310e
REDIM
311
MEM1
402
Anch
312
311a
311b
311c
EnvG1
EnvG2
EnvG3
315
313a
313b
313c
MEM2

FIG. 5A

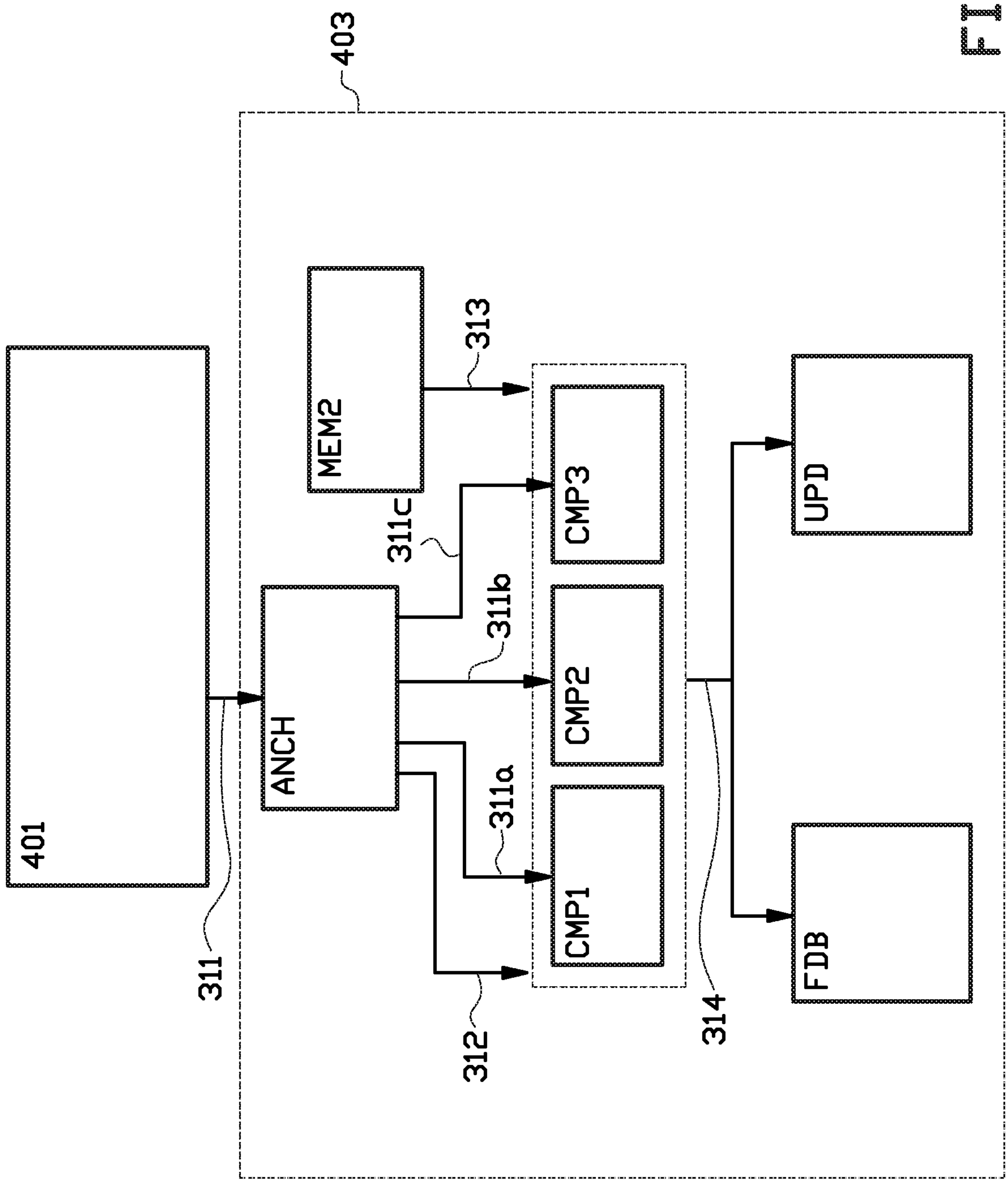
403
401
311
ANCH
MEM2
313
311c
311b
311a
312
CMP1
CMP2
CMP3
314
UPD
FDB

FIG. 5B

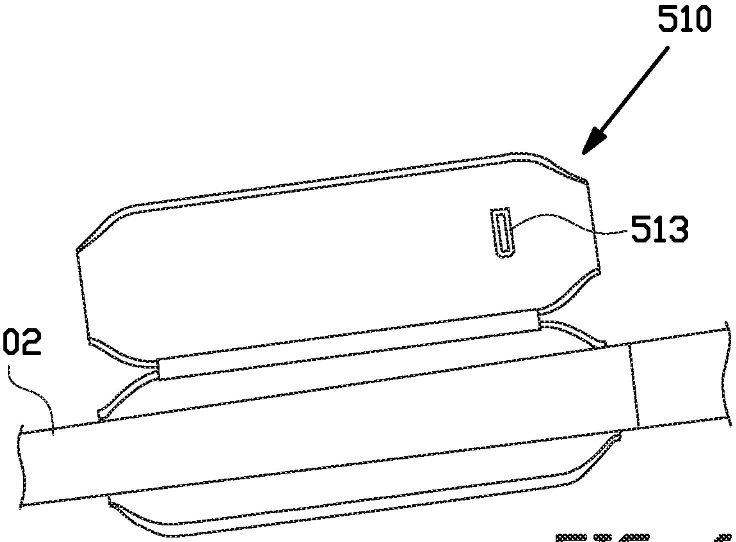


FIG. 6B

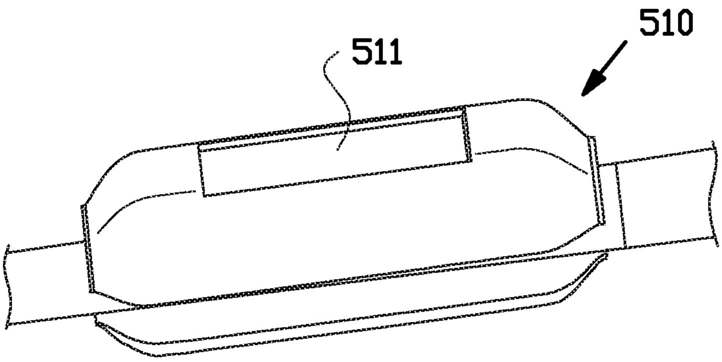


FIG. 6C

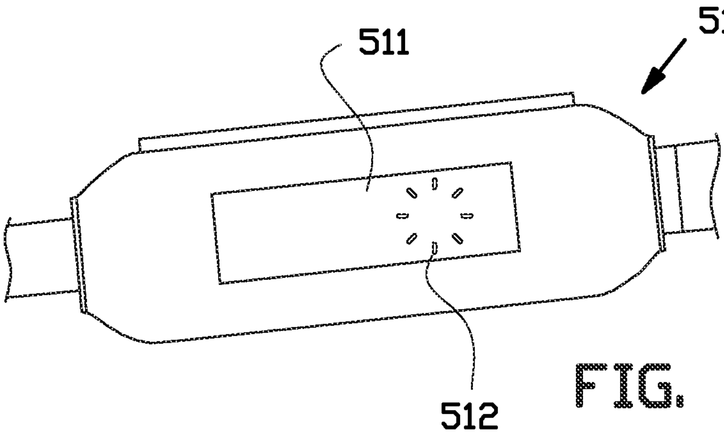


FIG. 6D

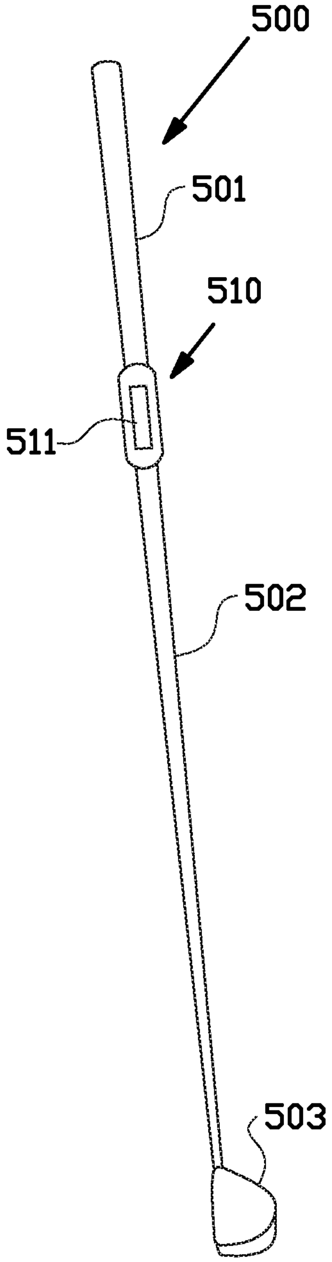


FIG. 6A

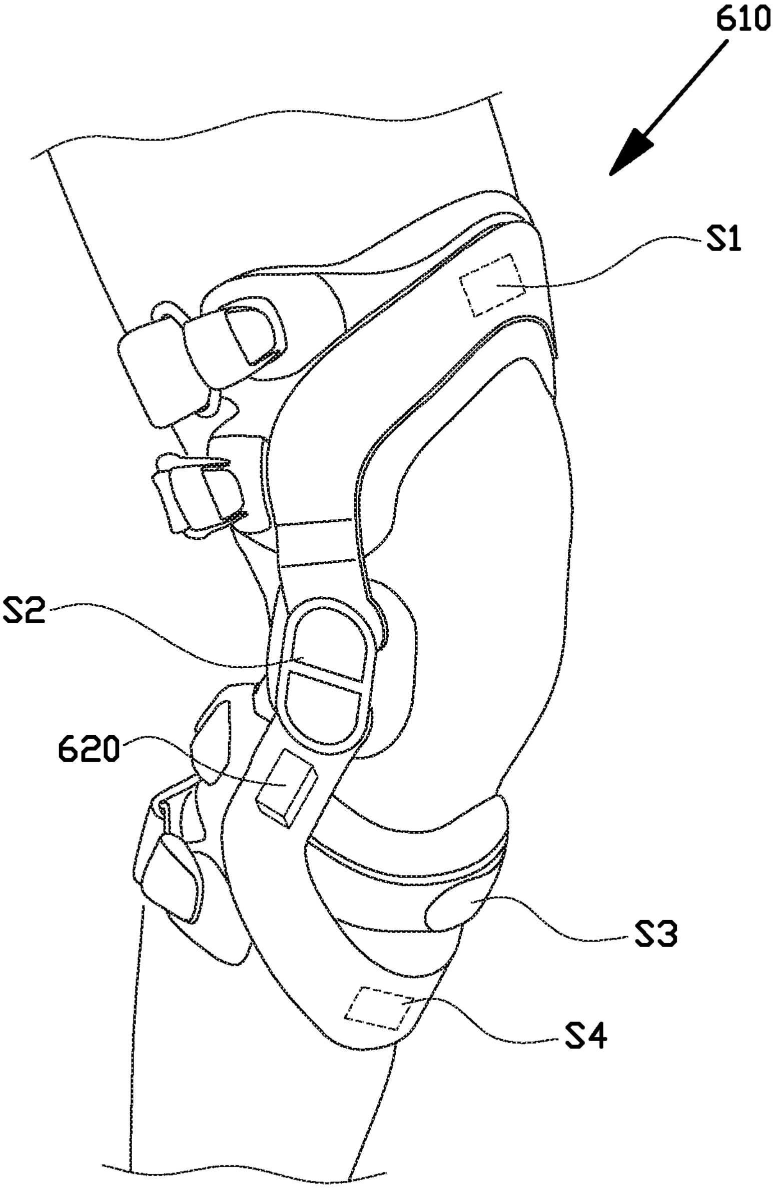


FIG. 7

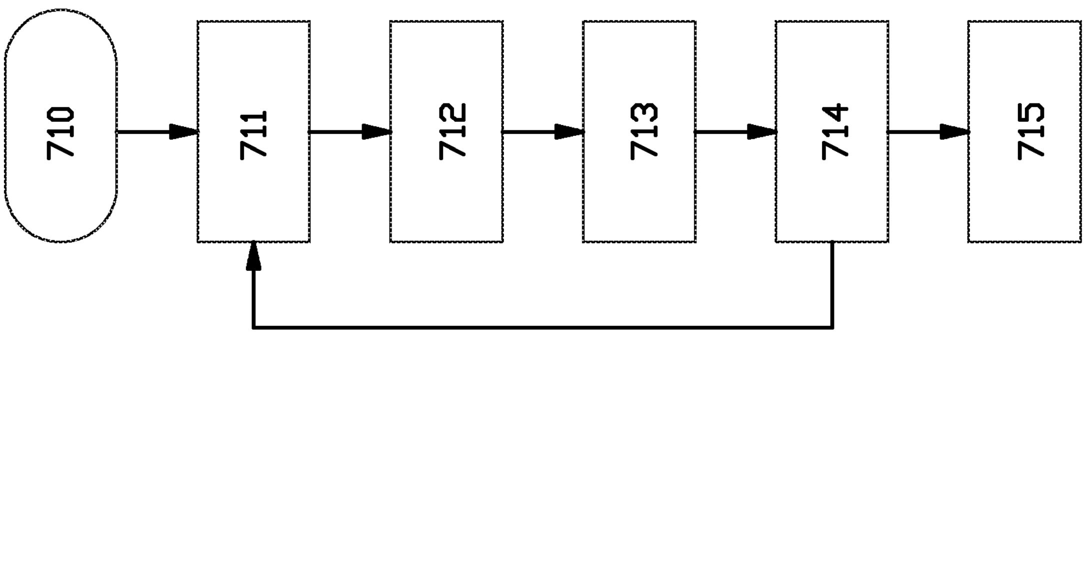


FIG. 8A

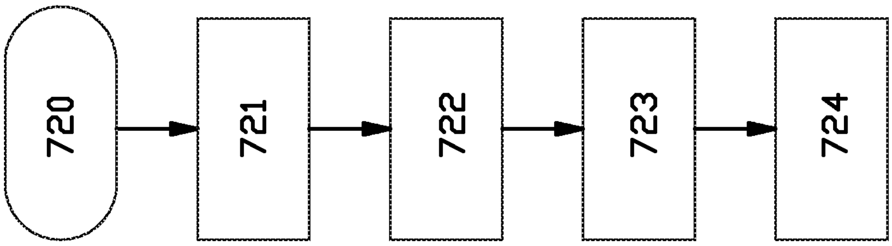


FIG. 8B

# INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2011/050305

A. CLASSIFICATION OF SUBJECT MATTER
INV. A63B24/00 A63B69/36
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A63B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | US 2009/005188 A1 (IWATSUBO TAKUZO [JP] ET AL) 1 January 2009 (2009-01-01) paragraphs [0086] - [0089], [0091], [0093], [0099]; claim 6 ----- | 1-19 |
| Y | US 2008/061949 A1 (FERGUSON KEVIN [US] ET AL) 13 March 2008 (2008-03-13) paragraphs [0012], [0024] - [0026], [0038], [0039], [0047], [0058] - [0061], [0093] - [0096], [0103], [0104], [0166], [0167]; claims 4,6,9; figures 3c,3d ----- | 1-19 |
| Y | WO 2009/034189 A1 (TECHNOLOGIES88 B V [NL]; VAN DER WERF GINA [NL]; VAN DIJK MARKUS [NL];) 19 March 2009 (2009-03-19) page 5; claim 3 ----- | 1-19 |
| | -/-- | |

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 27 June 2011 | 06/07/2011 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
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