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(71) Applicant *(for all designated States except US)*: **VORUM RESEARCH CORPORATION** [CA/CA]; 8765 Ash Street, Suite 6, Vancouver, British Columbia V6P 6T3 (CA).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **SABISTON, Robert Malcolm** [CA/CA]; 2545 W. 15th Avenue, Vancouver, British Columbia V6K 2Z3 (CA). **CHANG, Jeffrey David** [CA/CA]; 106 - 8450 Jellico Street, Vancouver, British Columbia V5S 4S9 (CA). **HANDFORD, Christopher Cameron** [CA/CA]; #2, 3315 West 6th Ave., Vancouver, British Columbia V6R 1T2 (CA).

(74) Agents: **CRAMER, Owen, W.** et al.; SMART & BIGGAR, 2200 - 650 West Georgia Street, Box 11560, Vancouver Centre, Vancouver, British Columbia V6B 4N8 (CA).

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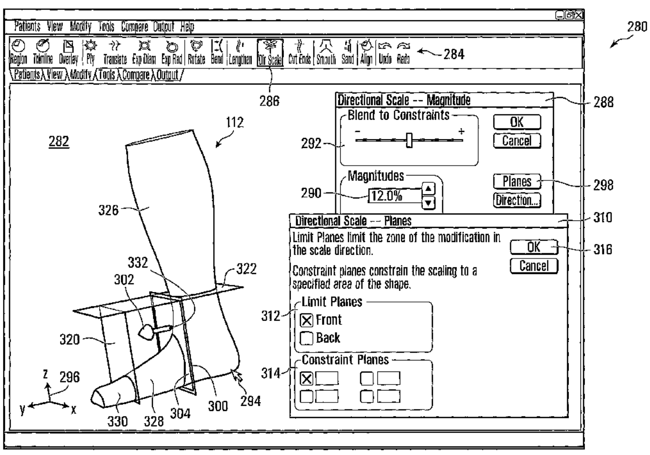

(57) Abstract: A method, apparatus, media and signals for applying a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body is disclosed. The representation is defined by an input plurality of coordinates representing a general shape of the appliance. The method involves identifying a coordinate location of a datum plane with respect to the representation of the appliance, the datum plane defining a transform volume within which the shape transformation is to be applied, the transform volume extending outwardly from and normal to a first surface of the datum plane. The method also involves identifying input coordinates in the plurality of input coordinates that are located within the transform volume. The method further involves modifying the identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance, and storing the modified representation of the appliance in a computer memory.

WO 2009/052602 A1

METHOD, APPARATUS, MEDIA, AND SIGNALS FOR APPLYING A SHAPE TRANSFORMATION TO A THREE DIMENSIONAL REPRESENTATION

BACKGROUND OF THE INVENTION

1. Field of Invention

This invention relates generally to three-dimensional shape representations and more particularly to applying a shape transformation to a representation of an appliance for a living body.

2. Description of Related Art

Prostheses and orthoses are commonly produced from three-dimensional representations of a body part of a human or an animal. The three-dimensional representation may then be manipulated on a computer using a three dimensional (3D) shape editing program to produce a modified representation of the body part. The modified representation may be used to generate instructions for controlling a carving machine that is configured to directly produce a prosthesis appliance from wood, or to produce a polyurethane mold for making an orthosis appliance, for example. An orthosis is an appliance that is applied externally to a body part to correct deformity, improve function, or relieve symptoms of a disease by supporting or assisting the musculo-neuro-skeletal system. A prosthesis is an appliance that replaces a missing body part.

The three-dimensional representation of the body part may be produced using a non-contact optical scanner that images the body part with a high level of accuracy. The scanner may include a laser for illuminating the body part with structured light and a video camera for capturing images of the illuminated body part. The captured images may then be processed to extract three-dimensional coordinates of the surface of the body part, which may be used in turn to produce the appliance.

SUMMARY OF THE INVENTION

Accordingly, the inventors have identified a need for modifying the three-dimensional representation, or a portion thereof, prior to producing the appliance. For example, where the appliance is an orthosis, it may be desirable to lengthen a portion of the foot to adapt the appliance for a patient having a larger shoe size. Other modifications may also be desired to provide a more comfortable fit to the patient, for example.

In accordance with one aspect of the invention there is provided a method for applying a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance. The method involves identifying a coordinate location of a datum plane with respect to the representation of the appliance, the datum plane defining a transform volume within which the shape transformation is to be applied, the transform volume extending outwardly from and normal to a first surface of the datum plane. The method also involves identifying input coordinates in the plurality of input coordinates that are located within the transform volume. The method further involves modifying the identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance, and storing the modified representation of the appliance in a computer memory.

Identifying the coordinate location of the datum plane may involve identifying a coordinate location that causes the datum plane to intersect the representation of the appliance such that the modified representation of the appliance includes a modified portion within the transform volume, and an unmodified portion outside the transform volume.

Modifying the identified input coordinates in accordance with the shape transformation may involve scaling the identified input coordinates in a direction normal to the first surface of the datum plane.

The method may involve identifying a location of at least one constraint plane, the at least one constraint plane being perpendicular to the datum plane and operable to limit an extent of the transform volume in a direction normal to the constraint plane.

Identifying the location of the at least one constraint plane may involve identifying respective locations of at least two constraint planes, each respective constraint plane being perpendicular to the datum plane, the respective constraint planes being orthogonally located with respect to each other.

Identifying the coordinate location of the constraint plane may involve identifying a coordinate location to cause the constraint plane to intersect the representation of the appliance such that the modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume.

The method may involve identifying a blending region in the transform volume proximate the constraint plane, and altering a shape transform magnitude in the blending region to cause continuity of shape between the modified portion and the unmodified portion of the modified representation of the appliance.

Modifying the identified input coordinates in accordance with the shape transformation may involve scaling the identified input coordinates in a direction normal to the first surface of the datum plane and altering the shape transform magnitude may involve applying a plurality of different scaling magnitudes to identified input coordinates in the blending region such that input coordinates in the blending region located proximate the constraint plane may be scaled less than input coordinates in the blending region that may be located distal to the constraint plane.

The method may involve identifying a location of a limit plane, the limit plane being located in the transform volume and being parallel to the datum plane, the limit plane being operable to limit an extent of the transform volume in a direction normal to the datum plane.

Identifying the coordinate location of the limit plane may involve identifying a coordinate location to cause the limit plane to intersect the representation of the appliance such that the modified representation of the appliance includes a modified portion within the transform volume, and an unmodified portion outside the transform volume, and may further involve identifying input coordinates in the plurality of input coordinates representing portions of the appliance located beyond the limit plane, and causing the identified input coordinates to be translated in a direction normal to the datum plane such that the modified portion of the representation and the unmodified portion of the representation of the appliance on either side of the limit plane remain contiguously located after the modifying.

Identifying the coordinate location of the datum plane may involve identifying the coordinate location of the datum plane in response to receiving first user input.

The method may involve displaying the representation of the appliance and the datum plane on a computer display.

The method may involve interactively repositioning the datum plane on the computer display in response to receiving second user input representing a desired change in the coordinate location of the datum plane.

Interactively repositioning the datum plane may involve repositioning the datum plane in response to user input representing at least one of a desired change to a pitch of the datum plane, a desired change to a roll of the datum plane, a desired change to a yaw of the datum plane, and a desired translation of the datum plane.

Modifying the identified input coordinates may involve generating a transform matrix representing the shape transform, and multiplying each identified input coordinate by the transform matrix to produce modified input coordinates representing the modified representation of the appliance.

The method may involve receiving the input plurality of points.

Receiving the input plurality of points may involve receiving a plurality of points from a three-dimensional surface scanner, the plurality of points representing at least one surface of the living body for which the appliance may be intended.

The method may involve transforming the modified representation of the appliance into a set of instructions operable to control a computer aided manufacturing machine to produce the appliance.

In accordance with another aspect of the invention there is provided an apparatus for applying a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance. The apparatus includes provisions for identifying a coordinate location of a datum plane with respect to the representation of the appliance, the datum plane defining a transform volume within which the shape transformation is to be applied, the transform volume extending outwardly from and normal to a first surface of the datum plane. The apparatus also includes provisions for identifying input coordinates in the plurality of input coordinates that are located within the transform volume. The apparatus further includes provisions for modifying the identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance, and provisions for storing the modified representation of the appliance in a computer memory.

The provisions for identifying the coordinate location of the datum plane may include provisions for identifying a coordinate location that causes the datum plane to intersect the representation of the appliance such that the modified representation of the appliance includes a modified portion within the transform volume, and an unmodified portion outside the transform volume.

The provisions for modifying the identified input coordinates in accordance with the shape transformation may include provisions for scaling the identified input coordinates in a direction normal to the first surface of the datum plane.

The apparatus may include provisions for identifying a location of at least one constraint plane, the at least one constraint plane being perpendicular to the datum plane and operable to limit an extent of the transform volume in a direction normal to the constraint plane.

The provisions for identifying the location of the at least one constraint plane may include provisions for identifying respective locations of at least two constraint planes, each respective constraint plane being perpendicular to the datum plane, the respective constraint planes being orthogonally located with respect to each other.

The provisions for identifying the coordinate location of the constraint plane may include provisions for identifying a coordinate location to cause the constraint plane to intersect the representation of the appliance such that the modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume.

The apparatus may include provisions for identifying a blending region in the transform volume proximate the constraint plane, and provisions for altering a shape transform magnitude in the blending region to cause continuity of shape between the modified portion and the unmodified portion of the modified representation of the appliance.

The provisions for modifying the identified input coordinates in accordance with the shape transformation may include provisions for scaling the identified input coordinates in a direction normal to the first surface of the datum plane and the provisions for altering the transform magnitude in the blending region may include provisions for applying a plurality of different scaling magnitudes to identified input coordinates in the blending region such that input coordinates in the blending region located proximate the constraint plane may be scaled less than input coordinates in the blending region that may be located distal to the constraint plane.

The apparatus may include provisions for identifying a location of a limit plane, the limit plane being located in the transform volume and being parallel to the datum plane, the limit plane being operable to limit an extent of the transform volume in a direction normal to the datum plane.

The provisions for identifying the coordinate location of the limit plane may include provisions for identifying a coordinate location to cause the limit plane to intersect the representation of the appliance such that the modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume, and may further include provisions for identifying input coordinates in the plurality of input coordinates representing portions of the appliance located beyond the limit plane, and provisions for causing the identified input coordinates to be translated in a direction normal to the datum plane such that the modified portion of the representation and the unmodified portion of the representation of the appliance on either side of the limit plane remain contiguously located after the modifying.

The provisions for identifying the coordinate location of the datum plane may include provisions for identifying the coordinate location of the datum plane in response to receiving first user input.

The apparatus may include provisions for displaying the representation of the appliance and the datum plane.

The apparatus may include provisions for interactively repositioning the datum plane on the provisions for displaying in response to receiving second user input representing a desired change in the coordinate location of the datum plane.

The provisions for interactively repositioning the datum plane may include provisions for repositioning the datum plane in response to user input representing at least one of a desired change to a pitch of the datum plane, a desired change to a roll of the datum plane, a desired change to a yaw of the datum plane, and a desired translation of the datum plane.

The provisions for modifying the identified input coordinates may include provisions for generating a transform matrix representing the shape transform, and provisions for multiplying each identified input coordinate by the transform matrix to produce modified input coordinates representing the modified representation of the appliance.

The apparatus may include provisions for receiving the input plurality of points.

Receiving the input plurality of points may include provisions for receiving a plurality of points from a three-dimensional surface scanner, the plurality of points representing at least one surface of the living body for which the appliance may be intended.

The apparatus may include provisions for transforming the modified representation of the appliance into a set of instructions operable to control a computer aided manufacturing machine to produce the appliance.

In accordance with another aspect of the invention there is provided an apparatus for applying a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance. The apparatus includes a processor circuit operably configured to identify a coordinate location of a datum plane with respect to the representation of the appliance, the datum plane defining a transform volume within which the shape transformation is to be applied, the transform volume extending outwardly from and normal to a first surface of the datum plane. The processor circuit is also operably configured to identify input coordinates in the plurality of input coordinates that are located within the transform volume. The processor circuit is further operably configured to modify the identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance, and store the modified representation of the appliance in a computer memory.

The processor circuit may be operably configured to identify a coordinate location that causes the datum plane to intersect the representation of the appliance such that the modified representation of the appliance includes a modified portion within the transform volume, and an unmodified portion outside the transform volume.

The processor circuit may be operably configured to modify the identified input coordinates in accordance with the shape transformation by scaling the identified input coordinates in a direction normal to the first surface of the datum plane.

The processor circuit may be operably configured to identify a location of at least one constraint plane, the at least one constraint plane being perpendicular to the datum plane and operable to limit an extent of the transform volume in a direction normal to the constraint plane.

The processor circuit may be operably configured to identify the location of the at least one constraint plane may include by identifying respective locations of at least two constraint planes, each respective constraint plane being perpendicular to the datum plane, the respective constraint planes being orthogonally located with respect to each other.

The processor circuit may be operably configured to identify the coordinate location of the constraint plane by identifying a coordinate location to cause the constraint plane to intersect the representation of the appliance such that the modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume.

The processor circuit may be operably configured to identify a blending region in the transform volume proximate the constraint plane, and alter a shape transform magnitude in the blending region to cause continuity of shape between the modified portion and the unmodified portion of the modified representation of the appliance.

The processor circuit may be operably configured to modify the identified input coordinates in accordance with the shape transformation by scaling the identified input coordinates in a direction normal to the first surface of the datum plane and the processor circuit may be operably configured to alter the transform magnitude in the blending region by applying a plurality of different scaling magnitudes to identified input coordinates in the blending region such that input coordinates in the blending region located proximate the constraint plane may be scaled less than input coordinates in the blending region that may be located distal to the constraint plane.

The processor circuit may be operably configured to identify a location of a limit plane, the limit plane being located in the transform volume and being parallel to the datum plane, the limit plane being operable to limit an extent of the transform volume in a direction normal to the datum plane.

The processor circuit may be operably configured to identify the coordinate location of the limit plane by identifying a coordinate location to cause the limit plane to intersect the representation of the appliance such that the modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume, and the processor circuit may be further operably configured to identify input coordinates in the plurality of input coordinates representing portions of the appliance located beyond the limit plane, and cause the identified input coordinates to be translated in a direction normal to the datum plane such that the modified portion of the representation and the unmodified portion of the representation of the appliance on either side of the limit plane remain contiguously located after the modifying.

The processor circuit may be operably configured to identify the coordinate location of the datum plane by identifying the coordinate location of the datum plane in response to receiving first user input.

The processor circuit may be operably configured to display the representation of the appliance and the datum plane.

The processor circuit may be operably configured to interactively reposition the datum plane on the provisions for displaying in response to receiving second user input representing a desired change in the coordinate location of the datum plane.

The processor circuit may be operably configured to interactively reposition the datum plane by repositioning the datum plane in response to user input representing at least one of a desired change to a pitch of the datum plane, a desired change to a roll of the datum plane, a desired change to a yaw of the datum plane, and a desired translation of the datum plane.

The processor circuit may be operably configured to modify the identified input coordinates by generating a transform matrix representing the shape transform, and multiplying each identified input coordinate by the transform matrix to produce modified input coordinates representing the modified representation of the appliance.

The processor circuit may be operably configured to receive the input plurality of points.

The processor circuit may be operably configured to receive the input plurality of points by receiving a plurality of points from a three-dimensional surface scanner, the plurality of points representing at least one surface of the living body for which the appliance may be intended.

The processor circuit may be operably configured to transform the modified representation of the appliance into a set of instructions operable to control a computer aided manufacturing machine to produce the appliance.

In accordance with another aspect of the invention there is provided a computer readable medium encoded with codes for directing a processor circuit to apply a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance. The codes direct the processor circuit to identify a coordinate location of a datum plane with respect to the representation of the appliance, the datum plane defining a transform volume within which the shape transformation is to be applied, the transform volume extending outwardly from and normal to a first surface of the datum plane. The codes also direct the processor circuit to identify input coordinates in the plurality of input coordinates that are located within the transform volume. The codes further direct the processor circuit to modify the identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance, and store the modified representation of the appliance in a computer memory.

In accordance with another aspect of the invention there is provided a computer readable signal encoded with codes for directing a processor circuit to apply a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance. The codes direct the processor circuit to identify a coordinate location of a datum plane with respect to the representation of the appliance, the datum plane defining a transform volume within which the shape transformation is to be applied, the transform volume extending outwardly from and normal to a first surface of the datum plane. The codes also direct the processor circuit to identify input coordinates in the plurality of input coordinates that are located within the transform volume. The codes further direct the processor circuit to modify the identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance, and store the modified representation of the appliance in a computer memory.

Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

In drawings which illustrate embodiments of the invention,

Figure **1** is a schematic view of a system for producing an appliance for a living body;

Figure **2** is a schematic view of a processor circuit for implementing an apparatus for applying a shape transformation to at least a portion of a representation of the appliance;

Figure **3** is a front perspective view of an exemplary polygon mesh representation of a limb;

Figure **4** is a flowchart representing blocks of codes for directing the processor circuit shown in Figure **2** to apply a shape transformation to the polygon mesh representation shown in Figure **3**;

Figure **5** is a flowchart representing blocks of codes for directing the processor circuit shown in Figure **2** to receive to receive an input plurality of coordinates representing a general shape of the appliance;

Figure **6** is a screenshot of a view of the exemplary limb representation shown in Figure **3**;

Figure **7A- 7B** is a flowchart representation of blocks of codes for directing the processor circuit shown in Figure **2** to identify a coordinate location of a datum plane;

Figure **8** is a flowchart representing blocks of codes for directing the processor circuit shown in Figure **2** to execute a process to identify input coordinates in the plurality of input coordinates that are located within a transform volume;

Figure **9** is a flowchart representing blocks of codes for directing the processor circuit shown in Figure **2** to modify the identified input coordinates in accordance with a shape transformation; and

Figure **10** is a screenshot of a view of a portion of the exemplary limb representation shown in Figure **3** and Figure **6**; and

Figure **11** is a flowchart representing blocks of codes for directing the processor circuit shown in Figure **2** to modify the identified input coordinates in accordance an alternative embodiment of the invention.

DETAILED DESCRIPTION

Referring to Figure **1**, a CAD/CAM (computer aided design/computer aided manufacturing) system for producing an appliance for a living body is shown generally at **100**. The system **100** includes a CAD apparatus **102** for applying a shape transformation to at least a portion of a representation of the appliance. The system **100** also includes a scanner **104**, and a computer aided manufacturing (CAM) machine **106**.

The apparatus **102** is in communication with the scanner **104** for receiving a signal encoded with an input plurality of coordinates representing a general shape of a part of a living body for which the appliance is to be produced. In the embodiment shown in Figure **1**, the body part is a lower limb **108** of a human patient, but in other embodiments the body part may be any part of a living body. Examples of suitable scanners include the FastSCAN Cobra handheld scanner manufactured by Polhemus of Colchester, Vermont, the Yeti Foot Scanner manufactured by Vorum Research Corporation of British Columbia, Canada, and the STARscanner™ manufactured by Orthomerica Products Inc. of California.

The apparatus **102** further includes a display **110** for displaying a three dimensional representation **112** of the limb **108**, and a processor circuit **114** for manipulating the input plurality of coordinates and/or the displayed representation of the limb. In this embodiment the apparatus **102** also includes a pointing device **116** having one or more actuator buttons for receiving user input from a user of the apparatus.

In general, when producing an appliance such as a prosthesis or orthosis, the input plurality of coordinates from the scanner **104** may be used as a starting point to which modifications are made using the CAD apparatus **102** to produce a modified representation of the appliance. The modified representation may include alterations to the shape of surfaces, such as compressions in areas of the body that tolerate pressure and/or relief in certain areas of the body that are sensitive to pressure, thus providing a comfortably fitting appliance as defined by the modified representation.

The CAM machine **106** generally includes a machine tool portion **118** for machining the appliance **120** from a material such as polyurethane foam or wood, for example. The machined appliance **120** has a shape defined by the modified representation of the appliance and generally corresponds to the shape of the body part, with alterations for fit, comfort, and/or support. The machined appliance **120** may be used directly as a prosthetic appliance. Alternatively, the machined appliance **120** may be used to mold a final appliance such as an orthosis, by molding a thermoplastic or other material over the machined appliance.

The CAM machine **106** also includes a controller **122** for controlling the machine tool portion **118** of the CAM machine. The controller **122** is in communication with the apparatus **102** for receiving a signal encoded with instructions operable to control the CAM machine **106** to produce the machined appliance **120**. An example of a suitable CAM machine is the CANFIT-PLUS™ Carver produced by Vorum Research Corporation of British Columbia, Canada.

<u>Processor Circuit</u>

The processor circuit **114** of the apparatus **102** is shown in greater detail in Figure **2** at **140**. Referring to Figure **2**, the processor circuit **140** includes a microprocessor **142**, a program memory **144**, a random access memory (RAM) **148**, a hard drive **150**, an input output port (I/O) **152**, and a media reader **154**, all of which are in communication with the microprocessor **142**.

Program codes for directing the microprocessor **142** to carry out various functions are stored in the program memory **144**, which may be implemented as a random access memory (RAM) and/or a hard disk drive (HDD), or a combination thereof. The program memory **144** includes a block of codes **172** for directing the microprocessor to provide general operating system (O/S) functions, and a block of codes **174** for directing the microprocessor **142** to provide functions to display a **3**D view of the representation of the limb **108** on the display **110**. The program memory **144** also includes a block of codes **176** for directing the microprocessor **142** to provide shape transformation functions for applying a shape transformation to at least a portion of the representation of the appliance.

The media reader **154** facilitates loading program codes into the program memory **144** from a computer readable medium **156**, such as a CD ROM disk **158**, or a computer readable signal **160**, such as may be received over a network such as the internet, for example.

The RAM **148** includes a plurality of storage locations including a store **180** for storing the input plurality of coordinates representing a general shape of the appliance (for example the limb **108**). The RAM **148** also includes a store **182** for storing an output plurality of points representing a modified representation of the appliance. The RAM **148** also includes a store **183** for storing a Boolean array of flags, having elements corresponding to the input coordinates. The RAM **148** further includes stores **184**, **186**, and **188** for storing coordinates identifying a datum plane, constraint planes, and limit planes respectively. The RAM **148** also includes a store **192** for storing a shape transform matrix, and a store **192** for storing blending function coefficients and parameters.

The I/O **152** includes a first interface **162** having an input **164** for receiving the signal encoded with the input plurality of points representing the shape of the limb **108**, and a second interface **166** having an output **168** for producing the signal encoded with the instructions for controlling the CAM machine **106** to produce the appliance. The interfaces **162** and **166** may be universal serial bus (USB) or an RS**232** serial interface for example. The I/O **152** also includes an output **170** for producing a display signal for causing a representation of the limb **108** to be displayed on the display **110**.

Coordinate representation of the appliance

The scanner **104** shown in Figure **1** may be configured to produce coordinates representing the limb **108** in any one of a plurality of existing data formats for representing surfaces of **3**D objects.

Referring to Figure **3**, in an exemplary embodiment, a surface of the limb **108** is represented by a generally tubular polygon mesh **200** having a plurality of quadrilateral polygons **202**, each polygon thus being defined by four vertices having respective (x,y,z) coordinates. The polygon mesh **200** includes *m* rows **214** of vertexes, where the vertexes are defined such that each row includes *n* entries. The vertices in each row are co-planar and may be stored an *mxn* array in the store **180** of the RAM **148** (shown in Figure **2**). Respective vertices in each row **214** are also contiguously located and as such, each quadrilateral polygon **202** in the mesh will be represented by vertices V(j,k), V(j,k+**1**), V(j+**1**,k) and V(j+**1**,k+**1**). For example, a polygon **204** is defined by a first vertex **206** (V(j,k)), a second vertex **208** (V(j,k+**1**)), a third vertex **210** (V(j+**1**,k)), and a fourth vertex **212** (V(j+**1**,k+**1**)). Additionally, since in this embodiment the polygon mesh **200** is tubular (and thus wraps around on itself), a final polygon in a row *j* will have vertices V(j,n), V(j,**0**), V(j+**1**,n) and V(j+**1**,**0**). Advantageously, in this exemplary embodiment, the connections between vertices is implicit in the *mxn* array data structure once the mesh dimensions have been selected, and it is thus not necessary to store additional connectivity information.

The polygon mesh **200** may be produced from data produced by the scanner **104**. Depending on the format of the data produced by the scanner **104**, the data may be resampled to produce the tubular polygon mesh **200** shown in Figure **3**.

In other embodiments the polygon mesh representing the shape of the limb **108** may be rectangular or otherwise shaped, or the mesh may be stored as an un-ordered set of vertices along with connectivity information. For example, an exemplary data structure for storing the vertices and identifying the polygons may include a first array of vertices (V**1** (x**1**, y**1**, z**1**), V**2**(x**2**, y**2**, z**2**) .... etc) and a second array defining which vertices make up each polygon (P**1** = (V**1**, V**2**, V**3**, V**4**)), P**2** = (V**3**, V**4**, V**5**, V**6**) .... etc).

In this embodiment, the data representation is ordered in a plurality of planes or slices **214**. Each plane **214** includes a plurality of co-planar vertices, and (x,y,z) coordinates of the points making up each plane may be stored as a row in a data array of at least two dimensions (not shown). Subsequent planes may be represented as successive rows in the data array. In the embodiment shown in Figure **3**, planes **214** are generally parallel to each other while other planes, such as planes **216**, may be disposed at an angle to each other.

Each plane **214** is thus represented by a plurality of vertices, which may be stored as rows of a two dimensional data array as $V_{1,1}$, $V_{1,2}$, $V_{1,3}$, ... $V_{i,j}$, where each $V_{i,j}$ represents (x,y,z) coordinates of the point on the plane **214**. Subsequent planes **214** may be represented by subsequent rows in the data array.

<u>Operation</u>

Referring to Figure **4**, a flowchart of blocks of codes for directing the microprocessor **142** (shown in Figure **2**) to apply a shape transformation to the polygon mesh representation **112** of the appliance, is shown generally at **240**. The actual code to implement each block may be written in any suitable program language, such as C, and/or C++, for example.

Prior to executing the shape transformation process, block **242** directs the microprocessor **142** to receive an input plurality of coordinates representing a general shape of the appliance.

The shape transformation process begins at block **244**, which directs the microprocessor **142** to identify a coordinate location of a datum plane with respect to the representation **112** of the appliance. The datum plane defines a transform volume within which the shape transformation is to be applied. The transform volume extends outwardly from and normal to a first surface of the datum plane.

Block **246** then directs the microprocessor **142** to identify input coordinates in the plurality of input coordinates that are located within the transform volume. Block **248** then directs the microprocessor **142** to modify the input coordinates identified at block **248** in accordance with the shape transformation to produce a modified representation of the appliance.

The process **240** then continues at block **250**, which directs the microprocessor **142** to store the modified representation of the appliance in a computer memory (for example the RAM **148**).

Advantageously, the process **240** defines a transform volume that facilitates application of shape transforms to only a desired portion of the appliance representation **112**, while other portions of the appliance representation may remain unaffected by the shape transformation.

Receiving the input plurality of coordinates

Block **242** of the process **240** (shown in Figure **4**) is shown in greater detail in Figure **6**. Referring to Figure **6**, a flowchart of blocks of codes for directing the microprocessor **142** (shown in Figure **2**) to receive the input plurality of coordinates representing the general shape of the appliance is shown generally at **260**.

The process begins at block **262**, which directs the microprocessor **142** to cause the I/O **152** to receive a signal encoded with data defining the input plurality of coordinates at the input **164** of the interface **162**. In this embodiment the signal received at the input **164** is produced by the scanner **104**. Alternatively, the input of plurality of coordinates may be read from a library of appliance shapes stored on the hard drive **150**, or read in by the media reader **154** from a computer readable medium **156**.

Block **264** then directs the microprocessor **142** to store the coordinates in the store **180** of the RAM **148**. Block **266** then directs the microprocessor **142** to launch the **3**D display program codes **174** in the program memory **144**, which provide functions for displaying the representation **112** of the appliance.

The process **260** continues at block **268**, which directs the microprocessor **142** to read the input plurality of coordinates from the store **180** of the RAM **148**. Block **270** then directs the microprocessor **142** to display the appliance representation **112** on the display **110**.

In general the **3**D display program codes **174** direct the microprocessor **142** to provide functions for viewing the appliance from a perspective point which may be selected in response to user input (received at the pointing device **116** for example), thus facilitating viewing of the body part from a plurality of different angles. The **3**D display program codes **174** may also provide functions such as shading of the polygon mesh to provide a more realistic view of the object than is provided by a polygon mesh view, such as that shown in Figure **3**.

Referring to Figure **4**, an exemplary screenshot of a representative view **112** of the limb **108** is shown generally at **280**. The view **280** includes a display area **282** for displaying the representation **112** of the limb **108** (or other body part) in a coordinate space indicated by the axes **296**. In this embodiment, the representation **112** is displayed as a polygon mesh which is shaded using a Gourand shading algorithm.

The view **280** also includes a control panel **284**. The control panel **284** includes various control buttons for manipulating the displayed representation **112**, including a button **286** for invoking the shape transformation program codes **176** (shown in Figure **2**). The view **280** also includes a cursor **294**, which is interactively positioned on the display are in response to user input received at the pointing device **116** (shown in Figure **1**). The view **280** also includes a pop-up window **288** for receiving user input of shape transformation parameters. In this embodiment the window **288** includes a field **290** for receiving a shape transformation magnitude change, which in this embodiment is a scaling magnitude. The window **288** also includes a slider control **292** for increasing or reducing a size of a blending region, and an activator button for activating a plane definition window, as will be described later herein.

The view **280** also includes a pop-up window **310** for receiving user input for locating planes that further define the extents of the transform volume. The planes pop-up window **310** is displayed in repose to activation of the "Planes" button **298**. The window **310** includes a set of checkboxes **312** for activating front and/or back limit planes, a set of checkboxes **314** for activating constraint planes, and an "OK" button **316** for accepting changes and closing the window.

Locating planes defining transform volume

Block **244** of the process **240** (shown in Figure **4**) is shown in greater detail in Figure **7**. Referring to Figure 7A, a flowchart of blocks of codes for directing the microprocessor **142** (shown in Figure **2**) to identify the coordinate location of the datum plane is shown generally at **350**.

The process begins at block **352** when the button **286** (shown in Figure **6**) is activated by the user, which directs the microprocessor **142** to launch the shape transformation program codes **176** stored in the program memory **144** (shown in Figure **2**).

Block **354** then directs the microprocessor **142** to display a datum plane **300** at a default location and to write coordinates identifying the default location to the store **184** in the RAM **148**. Block **356** directs the microprocessor **142** to receive user input, which in this embodiment is received from the pointing device **116** shown in Figure **2**.

The process then continues at block **358**, which directs the microprocessor to determine whether the user input represents a desired change to the desired location of the datum plane **300**. If the cursor **294** is positioned over the datum plane **300**, movements of the pointing device **116** are interpreted as a request to translate the location of the datum plane on the display. The datum plane **300** also includes an arrow **302** normal to a first surface **304** of the datum plane, and the orientation of the datum plane may be changed by when the cursor **294** is positioned over the arrow **302**, and the arrow is dragged to cause the datum plane to change orientation (i.e. pitch, roll and yaw). If at block **358** the user input represents a desired change to the location and/or orientation of the datum plane **300**, then the process continues at block **360**.

Block **360** directs the microprocessor **142** to move the datum plane **300** on the display area **282** in response to the user input, and to write new coordinates identifying the updated location and/or orientation of the datum plane to the store **184** in the RAM **148**. The datum plane may be represented by at least three coordinate locations of points lying in the datum plane **300**.

While the datum plane **300** is shown in Figure **4** as having limited extent, the outline shown only represents an active portion of the datum plane selected in accordance with a size of the displayed appliance **112**. The datum plane **300** defines the transform volume within which the shape transformation is to be applied. The transform volume extends outwardly from the first surface **304** of the datum plane in the direction of the arrow **302**. In the embodiment shown in Figure **4**, a medial portion of a foot and toe area of the appliance representation **112** are both within the transform volume.

If at block **358** the user input does not represent a desired change to the location and/or orientation of the datum plane **300**, then the process then continues at block **362**. Block **362** directs the microprocessor **142** to determine whether the user input represents a request to display a constraint plane or a limit plane. If the user input does not represent a request to display a constraint plane or a limit plane, then block **362** directs the microprocessor **142** back to block **356**.

If at block **362** the user input indicates that the "Planes" button **298** was activated, the block **362** directs the microprocessor **142** to display the planes pop-up window **310**. The process then continues at block **372** in Figure 7B.

Referring to Figure 7B, block **372** directs the microprocessor **142** to receive user input from the pointing device **116**. Block **374** then directs the microprocessor **142** to determine whether one of the limit plane checkboxes **312** or constraint plane checkboxes **314** have been activated. If one of the checkboxes are activated then the process continues at block **376**, which directs the microprocessor **142** to display the appropriate constraint or limit plane at a default location and to write coordinates identifying the default location to the respective store **186** or **188** in the RAM **148**.

Referring back to Figure **6**, in the embodiment shown, a “front” limit plane checkbox **312** is activated which causes a limit plane **320** to be displayed. One of the constraint checkboxes **314** is also checked, which causes a constraint plane **322** to be displayed.

Referring again to Figure **7B**, if at block **374** no checkbox is activated, then the process continues at block **378**, which directs the microprocessor **142** to determine whether a location of a displayed constraint or limit plane should be changed in response to the user input. If a location of one of the planes is to be changed then the process continues at block **380**, which directs the microprocessor **142** to move the appropriate plane and to write new coordinates to the respective store **186** or **188** in the RAM **148**. Block **380** then directs the microprocessor **142** back to block **372**.

If at block **378**, the user input does not represent a desired location change of plane location, then block **378** directs the microprocessor **142** back to block **372**.

In general constraint planes and limit planes limit the extent of the transform volume, within which the shape transformation is to be applied. Constraint planes, such as the constraint plane **322**, are perpendicular to the datum plane **300**. In this embodiment up to four orthogonally oriented constraint planes may be activated and displayed by selecting the checkboxes **314**. Each of the four constraint planes may be used to limit the extent of the transform volume in the respective orthogonal directions in which the respective constraint planes are oriented.

In the embodiment shown, the constraint plane **322** limits the transform volume such that a portion **326** of the representation **112** is outside the transform volume and is thus not modified by any shape transformation applied to the transform volume. A second portion **328** of the representation **112** is inside the transform volume and is modified by any applied shape transformations.

In this embodiment, a forward transform volume in the direction of the arrow **302** is active, and shape transformations are performed in a "forward direction". However, a reverse transform volume in an opposite direction to the arrow **302** may also be activated for shape transformation. Limit planes, such as the limit plane **320** are defined in either forward transform volume (i.e. the "front" checkbox **312** is activated), or in the reverse transform volume, in which case the "back" checkbox is activated.

The limit plane **320** intersects the representation **112** and limits the extent of the transform volume to a region between the limit plane **320**, the constraint plane **322**, and the datum plane. In the embodiment shown, the transform volume still extends without limit in a downward direction and directions into and out pf the drawing page, as constraint planes are not activated in these directions.

The limit plane **320** also demarcates a third portion **330** of the representation **112** from the second portion **328** of the representation. Input coordinates representing the third portion **330** of the representation **112** located beyond the limit plane **320** are outside the transform volume and the shape transformation is not applied to these coordinates. However since the shape transformation generally causes the second portion **328** to be altered in shape, after transformation, the third portion **330** requires translation in a direction normal to the datum plane **300**. The translation causes the second portion **328** and the third portion **330** of the representation **112** on either side of said limit plane to remain contiguously located after being modified by the shape transformation.

Once constraint and limit planes have been located as desired, the window **310** may be closed by activating the "OK" button **316**.

Identifying input coordinates in the transform volume

Block **246** of the process **240** (shown in Figure **4**) is shown in greater detail in Figure **8**. Referring to Figure **8**, a flowchart of blocks of codes for directing the microprocessor **142** (shown in Figure **2**) to identify input coordinates in the plurality of input coordinates that are located within the transform volume is shown generally at **390**.

The process **390** is launched when user input is received changing the shape transformation magnitude in the field **290**. Block **392** directs the microprocessor **142** to read a first input coordinate from the store **180** in the RAM **148**. Block **394** then directs the microprocessor **142** to determine whether the input coordinate read from the store **180** is located within the defined transform volume, in which case the process continues at block **396**.

Block **396** directs the microprocessor **142** to flag the input coordinate by writing a "**1**" to the Boolean array of flags in the store **183** of the RAM **148**. The process then continues at block **398**.

If at block **394**, the input coordinate is not located in the transform volume then block **394** directs the microprocessor **142** to block **398**.

Block **398** directs the microprocessor **142** to determine whether the input coordinate was the last input coordinate. If not, then the process continues at block **400**, which directs the microprocessor **142** to read the next input coordinate from the store **180** of the RAM **148**. Block **400** then directs the microprocessor **142** back to block **394**.

If at block **398** the input coordinate is the last input coordinate, then the process ends at **402**. Once the process **390** has completed, elements set to Boolean "**1**" in the coordinate flag array in the store **183** identify corresponding coordinates in the store **180**, as being located within the transform volume.

Modifying identified input coordinates

Block **248** of the process **240** (shown in Figure **4**) is shown in greater detail in Figure **9**. Referring to Figure **9**, a flowchart of blocks of codes for directing the microprocessor **142** (shown in Figure **2**) to modify the identified input coordinates in accordance with the shape transformation is shown generally at **420**.

The process **420** is launched after the process **390** has identified input coordinates located in the transform volume. The process begins at block **422**, which directs the microprocessor **142** to read the transform matrix from the store **190** in the RAM **148**.

In this embodiment the transformation matrix has the following form:

$$M = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 \\ a_{21} & a_{22} & a_{23} & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ T_x & T_y & T_z & 1 \end{bmatrix}, \qquad \text{Eqn } \mathbf{1}$$

and input coordinates may be represented in homogenous coordinates by the vector:

$$\overline{P} = [x \quad y \quad z \quad 1]. \qquad \text{Eqn } \mathbf{2}$$

Modified output coordinates $\overline{P}'$ my then be produced by multiplying the input coordinates $\overline{P}$ by the transformation matrix *M*:

$$\overline{P}' = \overline{P}M \qquad \text{Eqn } \mathbf{3}$$

The transformation matrix *M* is often represented in segmented form as:

$$M = \begin{bmatrix} \begin{bmatrix} & A & \end{bmatrix} & \begin{bmatrix} 0 \end{bmatrix} \\ \begin{bmatrix} & T & \end{bmatrix} & \begin{bmatrix} 1 \end{bmatrix} \end{bmatrix}, \qquad \text{Eqn } \mathbf{4}$$

where *A* is a **3x3** matrix having elements that represent combined effects of scaling, rotation, and shear transformations, *T* is a **3x1** vector having elements that represent translations of the input coordinate of the input, ***0*** is a **1x3** vector having zero value elements, and ***1*** is a **1x1** matrix having a single unity element.

For example, a rotation *θ* about the *z*-axis:

$$A = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix},$$

for a uniform scale in all directions:

$$A = \begin{bmatrix} s & 0 & 0 \\ 0 & s & 0 \\ 0 & 0 & s \end{bmatrix},$$

where *s* is a scale factor, and for a non-uniform scale in the x-axis direction:

$$A = \begin{bmatrix} s & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}.$$

The above examples all result in shape transformations with respect to the axes *x, y, or z*, which would require that the datum plane be aligned with one of the axes. Referring back to Figure **6**, for a scaling transformation with respect to an arbitrarily oriented datum plane **300** a point *Q* (**332**) that lies on the datum plane is selected and a unit vector $\bar{U}$ that is normal to the datum plane is defined (i.e. a unit vector in the direction of the arrow **302**), and the matrix *A* may then be written as:

$$A = I - (1-s)(\bar{U} \otimes \bar{U}), \qquad \text{Eqn } \mathbf{5}$$

where I is a **3**x**3** identity matrix, $\bar{U} \otimes \bar{U}$ is a tensor product of the unit vector $\bar{U}$ with itself, and *s* is a scaling factor having a scalar value representing a desired scale (i.e. when s=**1** there is no scaling of the input coordinates). The corresponding translation vector *T* may be written as:

$$T = (1-s)(Q\bar{U})\bar{U} \qquad \text{Eqn } \mathbf{6}$$

By substituting *A* obtained from equation **5** and *T* obtained from equation **6** into equation **4**, a transform matrix *M* is obtained that may be used to perform non-uniform scaling in a direction normal to the arbitrarily located datum plane **300**. The elements of the matrix *M* are stored in the RAM **148**.

Referring back to Figure **9**, the process **420** then continues at block **424**, which directs the microprocessor **142** to read the transform magnitude. The transform magnitude is received in response to user input received at field **290** of the window **288**, and stored in the store **190** of the RAM **148**.

Block **426** then directs the microprocessor **142** to read the first flagged input coordinate from the store **180** (i.e. a coordinate that has a corresponding flag set in the store **183** in the RAM **148**).

Block **428** then directs the microprocessor **142** to multiply the input coordinate by the transform matrix *M* to produce a first modified coordinate. Block **430** then directs the microprocessor **142** to store the modified coordinate as an output coordinate in the store **182** of the RAM **148**.

The process then continues at block **432**, which directs the microprocessor **142** to determine whether the input coordinate is the last flagged input coordinate in the store **180** of the RAM**148**. If the input coordinate is not the last flagged coordinate then the process continues at block **434**, which directs the microprocessor **142** to read the next flagged input coordinate from the store **180**. Block **434** then directs the microprocessor **142** back to block **428**.

If the input coordinate is the last flagged coordinate then the process ends at block **436**.

The process **420** by using the transform matrix *M* defined in equations **4**, **5**, and **6**, thus performs a shape transformation on the transform volume defined by the datum plane **300**, the limit plane **320**, and the constraint plane **322**. If *s* in Eqn **5** and **6** is greater than unity, then the second portion **328** of the representation **112** is enlarged in the direction of the arrow **302**, and the third portion **330** is translated in the direction of the arrow **302**. If *s* in Eqn **5** and **6** is less than unity, then the second portion **328** of the representation **112** is reduced in size, and the third portion **330** is translated in a direction opposite to the arrow **302**.

Blending

Referring to Figure **10**, an alternate exemplary embodiment of the representation **112** is shown generally at **440**, in which a datum plane **442** is shown in a different orientation to that shown in Figure **6**. In this embodiment the transform volume is defined in the direction of an arrow **443**, which is generally directed in lateral direction with respect to the representation **112**. A first constraint plane **444** and a second constraint plane **446** are also activated. Any shape transformation that may be applied within the transform volume may thus result in a discontinuity between an unmodified portion **448**, and a modified portion **450** of the representation **112**.

Referring to Figure **11**, a flowchart of blocks of codes for directing the microprocessor **142** (shown in Figure **2**) to modify the identified input coordinates in accordance an alternative embodiment is shown generally at **460**. The process **460** has several steps in common with the process **420** shown in Figure **9**, but additionally provides for blending at the constraint planes.

The process **460** begins at **462**, which directs the microprocessor **142** to read the transform matrix from the store **190** in the RAM **148**. Block **464** then directs the microprocessor **142** to read the transform magnitude. The transform magnitude is received in response to user input received at field **290** of the window **288**, and stored in the store **190** of the RAM **148**.

Block **466** then directs the microprocessor **142** to read the blending function from the store **192** of the RAM **148**. In general blending is applied to alter a shape transform magnitude in the blending region to cause continuity of shape between the modified portion **450** and the unmodified portion **448**. The blending slider control **292** (shown in Figure **6**) facilitates user control over an extent of the blending region. When the slider control **292** is dragged in the positive direction, the blending region extends further into the transform volume from the constraint planes. Similarly, when the slider control **292** is dragged in the negative direction, the blending region extent into the transform volume is reduced.

A blending function *G(P)* is used to modify the scaling factor *s* to produce a modified scaling factor s' as follows:

$$s' = 1 + (s-1)G(P) \qquad \text{Eqn } \mathbf{7}$$

In one embodiment the blending function *G(P)* is implemented using the cubic polynomial:

$$G(P) = 3\left(\frac{h}{h_c}\right)^2 - 2\left(\frac{h}{h_c}\right)^3, \qquad \text{Eqn } \mathbf{8}$$

where *h* is the offset distance between the applicable constraint plane and the point *P*, and h_c is the blending parameter which is set in response to user input received via the slider control **292**. For equation **8**, when $h = \mathbf{0}$ (i.e. at the constraint plane), *G(P)* = zero and when $h = h_c$ *G(P)* = **1**. Accordingly, at location in the transform volume beyond $h = h_c$, $s' = s$, and thus blending is discontinued.

In an alternative embodiment, the blending function may be implemented using a bi beta function which forces a surface derivative at $h = \mathbf{0}$ and $h = h_c$ to be zero.

Still referring to Figure **11**, block **466** directs the microprocessor **142** to read the slider control **292**, and to write the desired value of the blending parameter h_c into the store **192** of the RAM **148**.

Block **468** then directs the microprocessor **142** to read the first flagged input coordinate from the store **180** (i.e. a coordinate that has a corresponding flag set in the store **183** in the RAM **148**).

Block **470** then directs the microprocessor **142** to determine whether the flagged input coordinate is in the blending region specified by the blending parameter h_c, in which case the process continues at block **482**. Block **482** directs the microprocessor **142** to determine the offset distance of the coordinate from the respective datum, limit, or constraint plane.

Block **484** then directs the microprocessor **142** to calculate the value of s' from equations **7** and **8**, and to generate the transform matrix using equations **4** – **6** using the s' scale factor. The process then continues at blocks **428** – **436** as described above in connection with Figure **9** using the transform matrix generated at block **484** to transform the input coordinates resulting in a blended transition between the modified portion **450** and the unmodified portions **448** of the representation **112**.

If at block **470**, the flagged input coordinate is not in the blending region specified by the blending parameter h_c, then the process continues at blocks **428** – **436** as described above in connection with Figure **9** using the transform matrix read at block **462** to transform the input coordinates.

Advantageously, the above processes and apparatus facilitate definition of an arbitrary direction for applying a shape transformation to a **3**D representation by defining a transform volume. Furthermore, by facilitating limits and/or constraints to the transform volume, the shape transformation may be applied to only desired portions of the representation.

While specific embodiments of the invention have been described and illustrated, such embodiments should be considered illustrative of the invention only and not as limiting the invention as construed in accordance with the accompanying claims.

What is claimed is:

1. A method for applying a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance, the method comprising:

identifying a coordinate location of a datum plane with respect to the representation of the appliance, said datum plane defining a transform volume within which the shape transformation is to be applied, said transform volume extending outwardly from and normal to a first surface of said datum plane;

identifying input coordinates in the plurality of input coordinates that are located within said transform volume;

modifying said identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance; and

storing said modified representation of the appliance in a computer memory.

2. The method of claim **1** wherein identifying said coordinate location of said datum plane comprises identifying a coordinate location that causes said datum plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume, and an unmodified portion outside the transform volume.

3. The method of claim **2** wherein modifying said identified input coordinates in accordance with the shape transformation comprises scaling said identified input coordinates in a direction normal to said first surface of said datum plane.

4. The method of claim **1** further comprising identifying a location of at least one constraint plane, said at least one constraint plane being perpendicular to said datum plane and operable to limit an extent of said transform volume in a direction normal to said constraint plane.

5. The method of claim **4** wherein identifying said location of said at least one constraint plane comprises identifying respective locations of at least two constraint planes, each respective constraint plane being perpendicular to said datum plane, the respective constraint planes being orthogonally located with respect to each other.

6. The method of claim **5** wherein identifying said coordinate location of said constraint plane comprises identifying a coordinate location to cause said constraint plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume.

7. The method of claim **6** further comprising:

identifying a blending region in said transform volume proximate said constraint plane; and

altering a shape transform magnitude in said blending region to cause continuity of shape between said modified portion and said unmodified portion of the modified representation of the appliance.

8. The method of claim **7** wherein modifying said identified input coordinates in accordance with the shape transformation comprises scaling said identified input coordinates in a direction normal to said first surface of said datum plane and wherein altering said shape transform magnitude comprises applying a plurality of different scaling magnitudes to identified input coordinates in the blending region such that input coordinates in the blending region located proximate the constraint plane are scaled less than input coordinates in the blending region that are located distal to the constraint plane.

9. The method of claim **1** further comprising identifying a location of a limit plane, said limit plane being located in said transform volume and being parallel to said datum plane, said limit plane being operable to limit an extent of said transform volume in a direction normal to said datum plane.

10. The method of claim **9** wherein identifying said coordinate location of said limit plane comprises identifying a coordinate location to cause said limit plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume, and an unmodified portion outside the transform volume, and further comprising:

identifying input coordinates in the plurality of input coordinates representing portions of the appliance located beyond said limit plane; and causing said identified input coordinates to be translated in a direction normal to the datum plane such that said modified portion of said representation and said unmodified portion of said representation of the appliance on either side of said limit plane remain contiguously located after said modifying.

11. The method of claim **1** wherein identifying said coordinate location of said datum plane comprises identifying said coordinate location of said datum plane in response to receiving first user input.

12. The method of claim **11** further comprising displaying the representation of the appliance and the datum plane on a computer display.

13. The method of claim **12** further comprising interactively repositioning said datum plane on said computer display in response to receiving second user input representing a desired change in said coordinate location of said datum plane.

14. The method of claim **13** wherein interactively repositioning said datum plane comprises repositioning said datum plane in response to user input representing at least one of:

a desired change to a pitch of said datum plane;

a desired change to a roll of said datum plane;

a desired change to a yaw of said datum plane; and

a desired translation of said datum plane.

15. The method of claim **1** wherein modifying said identified input coordinates comprises:

generating a transform matrix representing said shape transform; and

multiplying each identified input coordinate by said transform matrix to produce modified input coordinates representing said modified representation of the appliance.

16. The method of claim **15** further comprising receiving said input plurality of points.

17. The method of claim **16** wherein receiving said input plurality of points comprises receiving a plurality of points from a three-dimensional surface scanner, said plurality of points representing at least one surface of the living body for which the appliance is intended.

18. The method of claim **1** further comprising transforming said modified representation of the appliance into a set of instructions operable to control a computer aided manufacturing machine to produce the appliance.

19. An apparatus for applying a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance, the apparatus comprising:

means for identifying a coordinate location of a datum plane with respect to the representation of the appliance, said datum plane defining a transform volume within which the shape transformation is to be applied, said transform volume extending outwardly from and normal to a first surface of said datum plane;

means for identifying input coordinates in the plurality of input coordinates that are located within said transform volume;

means for modifying said identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance; and

means for storing said modified representation of the appliance in a computer memory.

20. The apparatus of claim **19** wherein said means for identifying said coordinate location of said datum plane comprises means for identifying a coordinate location that causes said datum plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume, and an unmodified portion outside the transform volume.

21. The apparatus of claim **19** wherein said means for modifying said identified input coordinates in accordance with the shape transformation comprises means for scaling said identified input coordinates in a direction normal to said first surface of said datum plane.

22. The apparatus of claim **19** further comprising means for identifying a location of at least one constraint plane, said at least one constraint plane being perpendicular to said datum plane and operable to limit an extent of said transform volume in a direction normal to said constraint plane.

23. The apparatus of claim **22** wherein said means for identifying said location of said at least one constraint plane comprises means for identifying respective locations of at least two constraint planes, each respective constraint plane being perpendicular to said datum plane, the respective constraint planes being orthogonally located with respect to each other.

24. The apparatus of claim **23** wherein said means for identifying said coordinate location of said constraint plane comprises means for identifying a coordinate location to cause said constraint plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume.

25. The apparatus of claim **24** further comprising:

means for identifying a blending region in said transform volume proximate said constraint plane; and

means for altering a shape transform magnitude in said blending region to cause continuity of shape between said modified portion and said unmodified portion of the modified representation of the appliance.

26. The apparatus of claim **25** wherein said means for modifying said identified input coordinates in accordance with the shape transformation comprises means for scaling said identified input coordinates in a direction normal to said first surface of said datum plane and wherein said means for altering said transform magnitude in said blending region comprises means for applying a plurality of different scaling magnitudes to identified input coordinates in the blending region such that input coordinates in the blending region located proximate the constraint plane are scaled less than input coordinates in the blending region that are located distal to the constraint plane.

27. The apparatus of claim **19** further comprising means for identifying a location of a limit plane, said limit plane being located in said transform volume and being parallel to said datum plane, said limit plane being operable to limit an extent of said transform volume in a direction normal to said datum plane.

28. The apparatus of claim **27** wherein said means for identifying said coordinate location of said limit plane comprises means for identifying a coordinate location to cause said limit plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume, and further comprising:

means for identifying input coordinates in the plurality of input coordinates representing portions of the appliance located beyond said limit plane; and

means for causing said identified input coordinates to be translated in a direction normal to the datum plane such that said modified portion of said representation and said unmodified portion of said representation of the appliance on either side of said limit plane remain contiguously located after said modifying.

29. The apparatus of claim **19** wherein said means for identifying said coordinate location of said datum plane comprises means for identifying said coordinate location of said datum plane in response to receiving first user input.

30. The apparatus of claim **29** further comprising means for displaying the representation of the appliance and the datum plane.

31. The apparatus of claim **30** further comprising means for interactively repositioning said datum plane on said means for displaying in response to receiving second user input representing a desired change in said coordinate location of said datum plane.

32. The apparatus of claim **31** wherein said means for interactively repositioning said datum plane comprises means for repositioning said datum plane in response to user input representing at least one of:

a desired change to a pitch of said datum plane;

a desired change to a roll of said datum plane;

a desired change to a yaw of said datum plane; and

a desired translation of said datum plane.

33. The apparatus of claim **19** wherein said means for modifying said identified input coordinates comprises:

means for generating a transform matrix representing said shape transform; and

means for multiplying each identified input coordinate by said transform matrix to produce modified input coordinates representing said modified representation of the appliance.

34. The apparatus of claim **33** further comprising means for receiving said input plurality of points.

35. The apparatus of claim **34** wherein receiving said input plurality of points comprises means for receiving a plurality of points from a three-dimensional surface scanner, said plurality of points representing at least one surface of the living body for which the appliance is intended.

36. The apparatus of claim **19** further comprising means for transforming said modified representation of the appliance into a set of instructions operable to control a computer aided manufacturing machine to produce the appliance.

37. An apparatus for applying a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance, the apparatus comprising a processor circuit operably configured to:

identify a coordinate location of a datum plane with respect to the representation of the appliance, said datum plane defining a transform volume within which the shape transformation is to be applied, said transform volume extending outwardly from and normal to a first surface of said datum plane;

identify input coordinates in the plurality of input coordinates that are located within said transform volume;

modify said identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance; and

store said modified representation of the appliance in a computer memory.

38. The apparatus of claim **37** wherein said processor circuit is operably configured to identify a coordinate location that causes said datum plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume, and an unmodified portion outside the transform volume.

39. The apparatus of claim **37** wherein said processor circuit is operably configured to modify said identified input coordinates in accordance with the shape transformation by scaling said identified input coordinates in a direction normal to said first surface of said datum plane.

40. The apparatus of claim **37** wherein said processor circuit is operably configured to identify a location of at least one constraint plane, said at least one constraint plane being perpendicular to said datum plane and operable to limit an extent of said transform volume in a direction normal to said constraint plane.

41. The apparatus of claim **40** wherein said processor circuit is operably configured to identify said location of said at least one constraint plane comprises by identifying respective locations of at least two constraint planes, each respective constraint plane being perpendicular to said datum plane, the respective constraint planes being orthogonally located with respect to each other.

42. The apparatus of claim **41** wherein said processor circuit is operably configured to identify said coordinate location of said constraint plane by identifying a coordinate location to cause said constraint plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume.

43. The apparatus of claim **42** wherein said processor circuit is operably configured to:

identify a blending region in said transform volume proximate said constraint plane; and

alter a shape transform magnitude in said blending region to cause continuity of shape between said modified portion and said unmodified portion of the modified representation of the appliance.

44. The apparatus of claim **43** wherein said processor circuit is operably configured to modify said identified input coordinates in accordance with the shape transformation by scaling said identified input coordinates in a direction normal to said first surface of said datum plane and wherein said processor circuit is operably configured to alter said transform magnitude in said blending region by applying a plurality of different scaling magnitudes to identified input coordinates in the blending region such that input coordinates in the blending region located proximate the constraint plane are scaled less than input coordinates in the blending region that are located distal to the constraint plane.

45. The apparatus of claim **37** wherein said processor circuit is operably configured to identify a location of a limit plane, said limit plane being located in said transform volume and being parallel to said datum plane, said limit plane being operable to limit an extent of said transform volume in a direction normal to said datum plane.

46. The apparatus of claim **45** wherein said processor circuit is operably configured to identify said coordinate location of said limit plane by identifying a coordinate location to cause said limit plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume, and wherein said processor circuit is further operably configured to:

identify input coordinates in the plurality of input coordinates representing portions of the appliance located beyond said limit plane; and

cause said identified input coordinates to be translated in a direction normal to the datum plane such that said modified portion of said representation and said unmodified portion of said representation of the appliance on either side of said limit plane remain contiguously located after said modifying.

47. The apparatus of claim **37** wherein said processor circuit is operably configured to identify said coordinate location of said datum plane by identifying said coordinate location of said datum plane in response to receiving first user input.

48. The apparatus of claim **47** wherein said processor circuit is operably configured to display the representation of the appliance and the datum plane.

49. The apparatus of claim **48** wherein said processor circuit is operably configured to interactively reposition said datum plane on said means for displaying in response to receiving second user input representing a desired change in said coordinate location of said datum plane.

50. The apparatus of claim **49** wherein said processor circuit is operably configured to interactively reposition said datum plane by repositioning said datum plane in response to user input representing at least one of:

a desired change to a pitch of said datum plane;

a desired change to a roll of said datum plane;

a desired change to a yaw of said datum plane; and

a desired translation of said datum plane.

51. The apparatus of claim **37** wherein said processor circuit is operably configured to modify said identified input coordinates by:

generating a transform matrix representing said shape transform; and multiplying each identified input coordinate by said transform matrix to produce modified input coordinates representing said modified representation of the appliance.

52. The apparatus of claim **51** wherein said processor circuit is operably configured to receive said input plurality of points.

53. The apparatus of claim **52** wherein said processor circuit is operably configured to receive said input plurality of points by receiving a plurality of points from a three-dimensional surface scanner, said plurality of points representing at least one surface of the living body for which the appliance is intended.

54. The apparatus of claim **37** wherein said processor circuit is operably configured to transform said modified representation of the appliance into a set of instructions operable to control a computer aided manufacturing machine to produce the appliance.

55. A computer readable medium encoded with codes for directing a processor circuit to apply a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance, the codes directing the processor circuit to:

identify a coordinate location of a datum plane with respect to the representation of the appliance, said datum plane defining a transform volume within which the shape transformation is to be applied, said transform volume extending outwardly from and normal to a first surface of said datum plane;

identify input coordinates in the plurality of input coordinates that are located within said transform volume;

modify said identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance; and

store said modified representation of the appliance in a computer memory.

56. A computer readable signal encoded with codes for directing a processor circuit to apply a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance, the codes directing the processor circuit to:

identify a coordinate location of a datum plane with respect to the representation of the appliance, said datum plane defining a transform volume within which the shape transformation is to be applied, said transform volume extending outwardly from and normal to a first surface of said datum plane;

identify input coordinates in the plurality of input coordinates that are located within said transform volume;

modify said identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance; and

store said modified representation of the appliance in a computer memory.

AMENDED CLAIMS

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(20.02.2009)

What is claimed is:

1. A method for applying a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance, the method comprising:

identifying a coordinate location of a datum plane with respect to the representation of the appliance, said datum plane defining a transform volume within which the shape transformation is to be applied, said transform volume extending outwardly from said datum plane in a normal direction to a first surface of said datum plane, said normal direction defining a direction for applying said shape transformation;

identifying input coordinates in the plurality of input coordinates that are located within said transform volume;

modifying said identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance; and

storing said modified representation of the appliance in a computer memory.

2. The method of claim **1** wherein identifying said coordinate location of said datum plane comprises identifying a coordinate location that causes said datum plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume, and an unmodified portion outside the transform volume.

3. The method of claim 2 wherein modifying said identified input coordinates in accordance with the shape transformation comprises scaling said identified input coordinates in a direction normal to said first surface of said datum plane.

4. The method of claim 1 further comprising identifying a location of at least one constraint plane, said at least one constraint plane being perpendicular to said datum plane and operable to limit an extent of said transform volume in a direction normal to said constraint plane.

5. The method of claim 4 wherein identifying said location of said at least one constraint plane comprises identifying respective locations of at least two constraint planes, each respective constraint plane being perpendicular to said datum plane, the respective constraint planes being orthogonally located with respect to each other.

6. The method of claim 5 wherein identifying said coordinate location of said constraint plane comprises identifying a coordinate location to cause said constraint plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume.

7. The method of claim 6 further comprising:

identifying a blending region in said transform volume proximate said constraint plane; and

altering a shape transform magnitude in said blending region to cause continuity of shape between said modified portion and said unmodified portion of the modified representation of the appliance.

8. The method of claim **7** wherein modifying said identified input coordinates in accordance with the shape transformation comprises scaling said identified input coordinates in a direction normal to said first surface of said datum plane and wherein altering said shape transform magnitude comprises applying a plurality of different scaling magnitudes to identified input coordinates in the blending region such that input coordinates in the blending region located proximate the constraint plane are scaled less than input coordinates in the blending region that are located distal to the constraint plane.

9. The method of claim **1** further comprising identifying a location of a limit plane, said limit plane being located in said transform volume and being parallel to said datum plane, said limit plane being operable to limit an extent of said transform volume in a direction normal to said datum plane.

10. The method of claim **9** wherein identifying said coordinate location of said limit plane comprises identifying a coordinate location to cause said limit plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume, and an unmodified portion outside the transform volume, and further comprising:

identifying input coordinates in the plurality of input coordinates representing portions of the appliance located beyond said limit plane; and causing said identified input coordinates to be translated in a direction normal to the datum plane such that said modified portion of said representation and said unmodified portion of said representation of the appliance on either side of said limit plane remain contiguously located after said modifying.

11. The method of claim **1** wherein identifying said coordinate location of said datum plane comprises identifying said coordinate location of said datum plane in response to receiving first user input.

12. The method of claim **11** further comprising displaying the representation of the appliance and the datum plane on a computer display.

13. The method of claim **12** further comprising interactively repositioning said datum plane on said computer display in response to receiving second user input representing a desired change in said coordinate location of said datum plane.

14. The method of claim **13** wherein interactively repositioning said datum plane comprises repositioning said datum plane in response to user input representing at least one of:

a desired change to a pitch of said datum plane;

a desired change to a roll of said datum plane;

a desired change to a yaw of said datum plane; and

a desired translation of said datum plane.

15. The method of claim **1** wherein modifying said identified input coordinates comprises:

generating a transform matrix representing said shape transform; and

multiplying each identified input coordinate by said transform matrix to produce modified input coordinates representing said modified representation of the appliance.

16. The method of claim **15** further comprising receiving said input plurality of points.

17. The method of claim **16** wherein receiving said input plurality of points comprises receiving a plurality of points from a three-dimensional surface scanner, said plurality of points representing at least one surface of the living body for which the appliance is intended.

18. The method of claim **1** further comprising transforming said modified representation of the appliance into a set of instructions operable to control a computer aided manufacturing machine to produce the appliance.

19. An apparatus for applying a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance, the apparatus comprising:

means for identifying a coordinate location of a datum plane with respect to the representation of the appliance, said datum plane defining a transform volume within which the shape transformation is to be applied, said transform volume extending outwardly from said datum plane in a normal direction to a first surface of said datum plane, said normal direction defining a direction for applying said shape transformation;

means for identifying input coordinates in the plurality of input coordinates that are located within said transform volume;

means for modifying said identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance; and

means for storing said modified representation of the appliance in a computer memory.

20. The apparatus of claim **19** wherein said means for identifying said coordinate location of said datum plane comprises means for identifying a coordinate location that causes said datum plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume, and an unmodified portion outside the transform volume.

21. The apparatus of claim **19** wherein said means for modifying said identified input coordinates in accordance with the shape transformation comprises means for scaling said identified input coordinates in a direction normal to said first surface of said datum plane.

22. The apparatus of claim **19** further comprising means for identifying a location of at least one constraint plane, said at least one constraint plane being perpendicular to said datum plane and operable to limit an extent of said transform volume in a direction normal to said constraint plane.

23. The apparatus of claim **22** wherein said means for identifying said location of said at least one constraint plane comprises means for identifying respective locations of at least two constraint planes, each respective constraint plane being perpendicular to said datum plane, the respective constraint planes being orthogonally located with respect to each other.

24. The apparatus of claim **23** wherein said means for identifying said coördinate location of said constraint plane comprises means for identifying a coordinate location to cause said constraint plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume.

25. The apparatus of claim **24** further comprising:

means for identifying a blending region in said transform volume proximate said constraint plane; and

means for altering a shape transform magnitude in said blending region to cause continuity of shape between said modified portion and said unmodified portion of the modified representation of the appliance.

26. The apparatus of claim **25** wherein said means for modifying said identified input coordinates in accordance with the shape transformation comprises means for scaling said identified input coordinates in a direction normal to said first surface of said datum plane and wherein said means for altering said transform magnitude in said blending region comprises means for applying a plurality of different scaling magnitudes to identified input coordinates in the blending region such that input coordinates in the blending region located proximate the constraint plane are scaled less than input coordinates in the blending region that are located distal to the constraint plane.

27. The apparatus of claim **19** further comprising means for identifying a location of a limit plane, said limit plane being located in said transform volume and being parallel to said datum plane, said limit plane being operable to limit an extent of said transform volume in a direction normal to said datum plane.

28. The apparatus of claim **27** wherein said means for identifying said coordinate location of said limit plane comprises means for identifying a coordinate location to cause said limit plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume, and further comprising:

means for identifying input coordinates in the plurality of input coordinates representing portions of the appliance located beyond said limit plane; and

means for causing said identified input coordinates to be translated in a direction normal to the datum plane such that said modified portion of said representation and said unmodified portion of said representation of the appliance on either side of said limit plane remain contiguously located after said modifying.

29. The apparatus of claim **19** wherein said means for identifying said coordinate location of said datum plane comprises means for identifying said coordinate location of said datum plane in response to receiving first user input.

30. The apparatus of claim **29** further comprising means for displaying the representation of the appliance and the datum plane.

31. The apparatus of claim **30** further comprising means for interactively repositioning said datum plane on said means for displaying in response to receiving second user input representing a desired change in said coordinate location of said datum plane.

32. The apparatus of claim **31** wherein said means for interactively repositioning said datum plane comprises means for repositioning said datum plane in response to user input representing at least one of:

a desired change to a pitch of said datum plane;

a desired change to a roll of said datum plane;

a desired change to a yaw of said datum plane; and

a desired translation of said datum plane.

33. The apparatus of claim **19** wherein said means for modifying said identified input coordinates comprises:

means for generating a transform matrix representing said shape transform; and

means for multiplying each identified input coordinate by said transform matrix to produce modified input coordinates representing said modified representation of the appliance.

34. The apparatus of claim **33** further comprising means for receiving said input plurality of points.

35. The apparatus of claim **34** wherein receiving said input plurality of points comprises means for receiving a plurality of points from a three-dimensional surface scanner, said plurality of points representing at least one surface of the living body for which the appliance is intended.

36. The apparatus of claim **19** further comprising means for transforming said modified representation of the appliance into a set of instructions operable to control a computer aided manufacturing machine to produce the appliance.

37. An apparatus for applying a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance, the apparatus comprising a processor circuit operably configured to:

identify a coordinate location of a datum plane with respect to the representation of the appliance, said datum plane defining a transform volume within which the shape transformation is to be applied, said transform volume extending outwardly from said datum plane in a normal direction to a first surface of said datum plane said normal direction defining a direction for applying said shape transformation;

identify input coordinates in the plurality of input coordinates that are located within said transform volume;

modify said identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance; and

store said modified representation of the appliance in a computer memory.

38. The apparatus of claim **37** wherein said processor circuit is operably configured to identify a coordinate location that causes said datum plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume, and an unmodified portion outside the transform volume.

39. The apparatus of claim **37** wherein said processor circuit is operably configured to modify said identified input coordinates in accordance with the shape transformation by scaling said identified input coordinates in a direction normal to said first surface of said datum plane.

40. The apparatus of claim **37** wherein said processor circuit is operably configured to identify a location of at least one constraint plane, said at least one constraint plane being perpendicular to said datum plane and operable to limit an extent of said transform volume in a direction normal to said constraint plane.

41. The apparatus of claim **40** wherein said processor circuit is operably configured to identify said location of said at least one constraint plane comprises by identifying respective locations of at least two constraint planes, each respective constraint plane being perpendicular to said datum plane, the respective constraint planes being orthogonally located with respect to each other.

42. The apparatus of claim **41** wherein said processor circuit is operably configured to identify said coordinate location of said constraint plane by identifying a coordinate location to cause said constraint plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume.

43. The apparatus of claim **42** wherein said processor circuit is operably configured to:

identify a blending region in said transform volume proximate said constraint plane; and

alter a shape transform magnitude in said blending region to cause continuity of shape between said modified portion and said unmodified portion of the modified representation of the appliance.

44. The apparatus of claim **43** wherein said processor circuit is operably configured to modify said identified input coordinates in accordance with the shape transformation by scaling said identified input coordinates in a direction normal to said first surface of said datum plane and wherein said processor circuit is operably configured to alter

said transform magnitude in said blending region by applying a plurality of different scaling magnitudes to identified input coordinates in the blending region such that input coordinates in the blending region located proximate the constraint plane are scaled less than input coordinates in the blending region that are located distal to the constraint plane.

45. The apparatus of claim **37** wherein said processor circuit is operably configured to identify a location of a limit plane, said limit plane being located in said transform volume and being parallel to said datum plane, said limit plane being operable to limit an extent of said transform volume in a direction normal to said datum plane.

46. The apparatus of claim **45** wherein said processor circuit is operably configured to identify said coordinate location of said limit plane by identifying a coordinate location to cause said limit plane to intersect the representation of the appliance such that said modified representation of the appliance includes a modified portion within the transform volume and an unmodified portion outside the transform volume, and wherein said processor circuit is further operably configured to:

identify input coordinates in the plurality of input coordinates representing portions of the appliance located beyond said limit plane; and

cause said identified input coordinates to be translated in a direction normal to the datum plane such that said modified portion of said representation and said unmodified portion of said representation of the appliance on either side of said limit plane remain contiguously located after said modifying.

47. The apparatus of claim **37** wherein said processor circuit is operably configured to identify said coordinate location of said datum plane by identifying said coordinate location of said datum plane in response to receiving first user input.

48. The apparatus of claim **47** wherein said processor circuit is operably configured to display the representation of the appliance and the datum plane.

49. The apparatus of claim **48** wherein said processor circuit is operably configured to interactively reposition said datum plane on said means for displaying in response to receiving second user input representing a desired change in said coordinate location of said datum plane.

50. The apparatus of claim **49** wherein said processor circuit is operably configured to interactively reposition said datum plane by repositioning said datum plane in response to user input representing at least one of:

a desired change to a pitch of said datum plane;

a desired change to a roll of said datum plane;

a desired change to a yaw of said datum plane; and

a desired translation of said datum plane.

51. The apparatus of claim **37** wherein said processor circuit is operably configured to modify said identified input coordinates by:

generating a transform matrix representing said shape transform; and multiplying each identified input coordinate by said transform matrix to produce modified input coordinates representing said modified representation of the appliance.

52. The apparatus of claim **51** wherein said processor circuit is operably configured to receive said input plurality of points.

53. The apparatus of claim **52** wherein said processor circuit is operably configured to receive said input plurality of points by receiving a plurality of points from a three-dimensional surface scanner, said plurality of points representing at least one surface of the living body for which the appliance is intended.

54. The apparatus of claim **37** wherein said processor circuit is operably configured to transform said modified representation of the appliance into a set of instructions operable to control a computer aided manufacturing machine to produce the appliance.

55. A computer readable medium encoded with codes for directing a processor circuit to apply a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance, the codes directing the processor circuit to:

identify a coordinate location of a datum plane with respect to the representation of the appliance, said datum plane defining a transform volume within which the shape transformation is to be applied, said transform volume extending outwardly from said datum plane in a normal direction to a first surface of said datum plane, said normal direction defining a direction for applying said shape transformation;

identify input coordinates in the plurality of input coordinates that are located within said transform volume;

modify said identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance; and

store said modified representation of the appliance in a computer memory.

56. A computer readable signal encoded with codes for directing a processor circuit to apply a shape transformation to at least a portion of a three dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates representing a general shape of the appliance, the codes directing the processor circuit to:

identify a coordinate location of a datum plane with respect to the representation of the appliance, said datum plane defining a transform volume within which the shape transformation is to be applied, said transform volume extending outwardly from said datum plane in a normal direction to a first surface of said datum plane, said normal direction defining a direction for applying said shape transformation;

identify input coordinates in the plurality of input coordinates that are located within said transform volume;

modify said identified input coordinates in accordance with the shape transformation to produce a modified representation of the appliance; and

store said modified representation of the appliance in a computer memory.

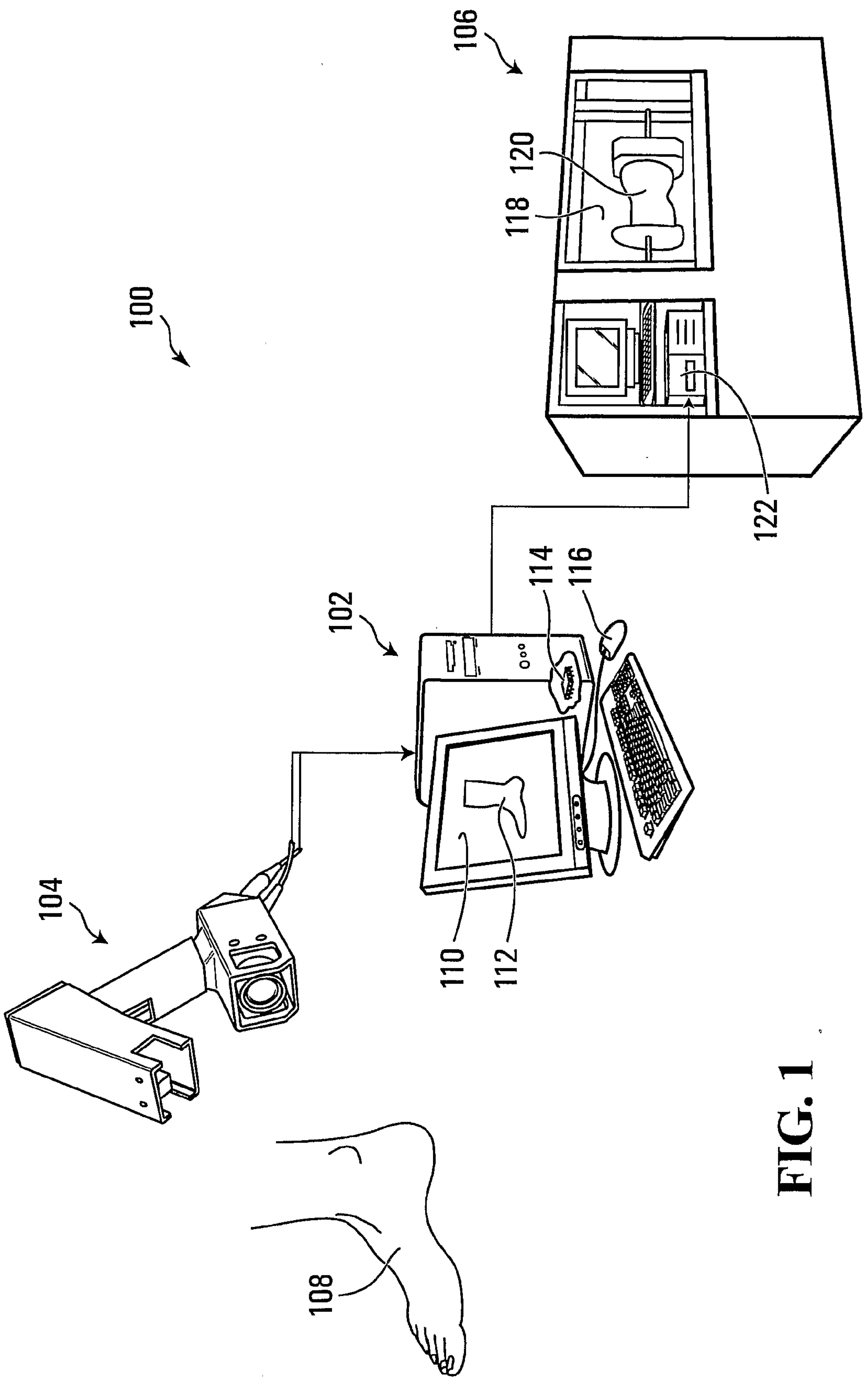

FIG. 1

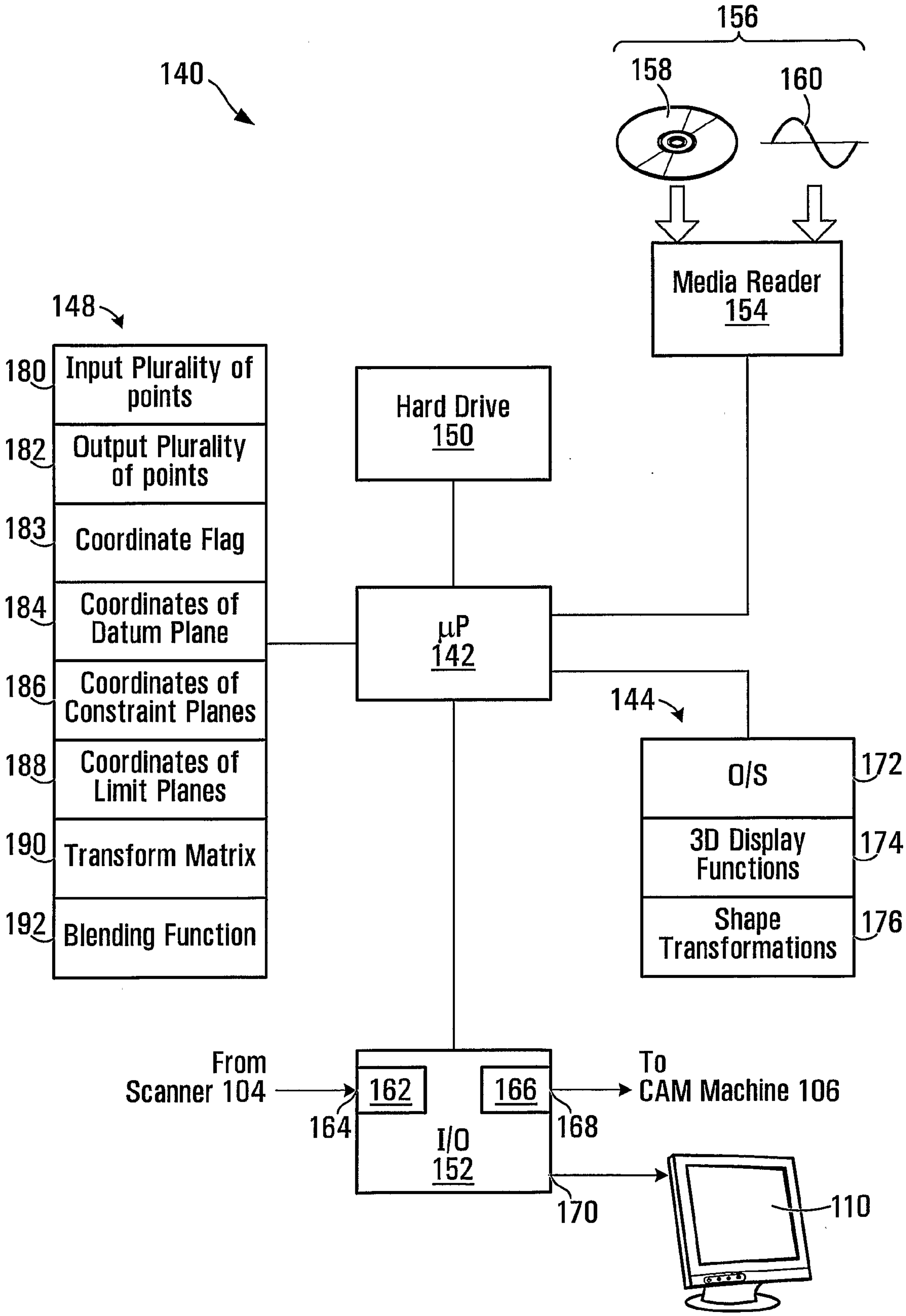
140
156
158
160
Media Reader
154
148
180
Input Plurality of points
182
Output Plurality of points
183
Coordinate Flag
184
Coordinates of Datum Plane
186
Coordinates of Constraint Planes
188
Coordinates of Limit Planes
190
Transform Matrix
192
Blending Function
Hard Drive
150
μP
142
144
O/S
172
3D Display Functions
174
Shape Transformations
176
From
Scanner 104
162
164
166
168
To
CAM Machine 106
I/O
152
170
110

FIG. 2

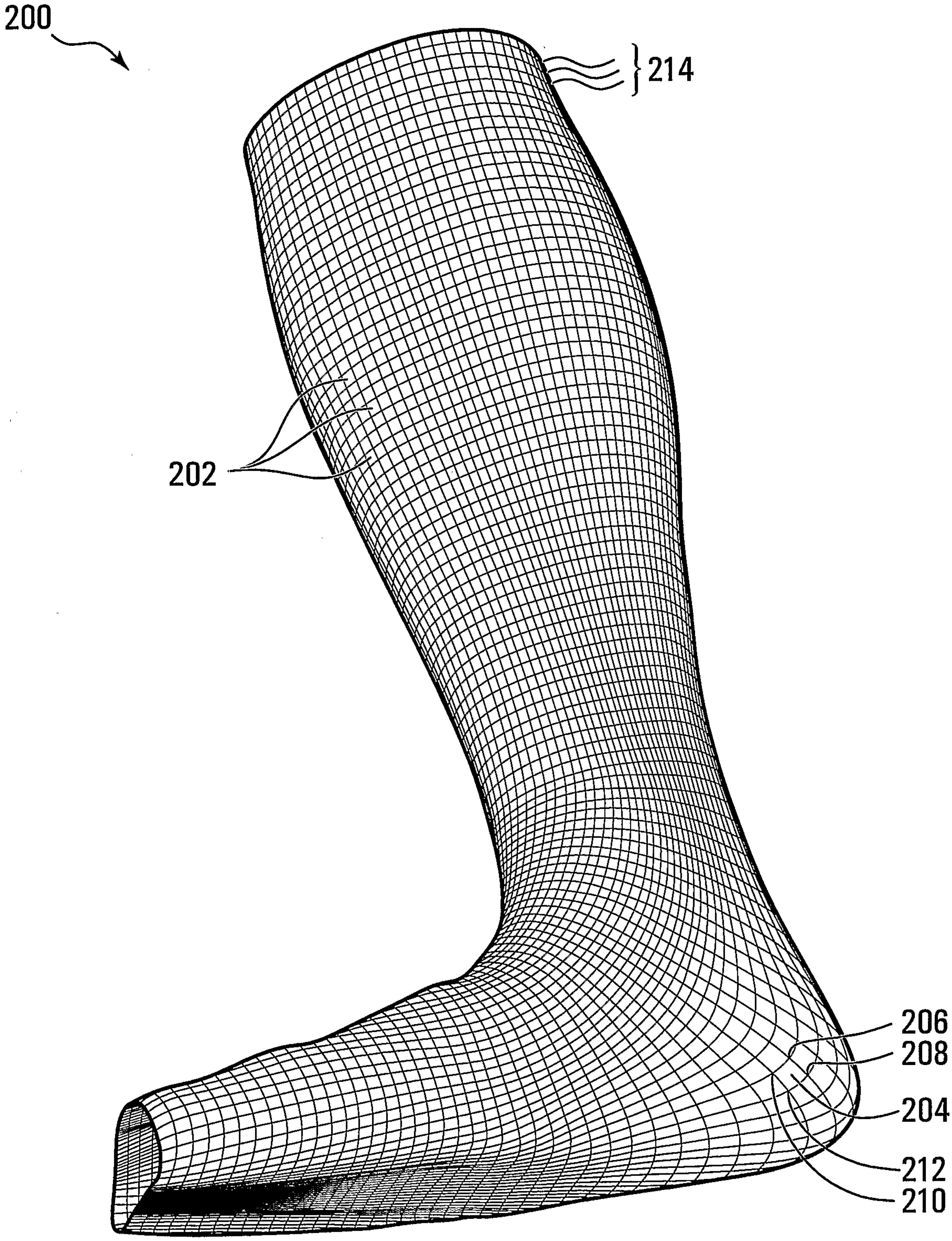

FIG. 3

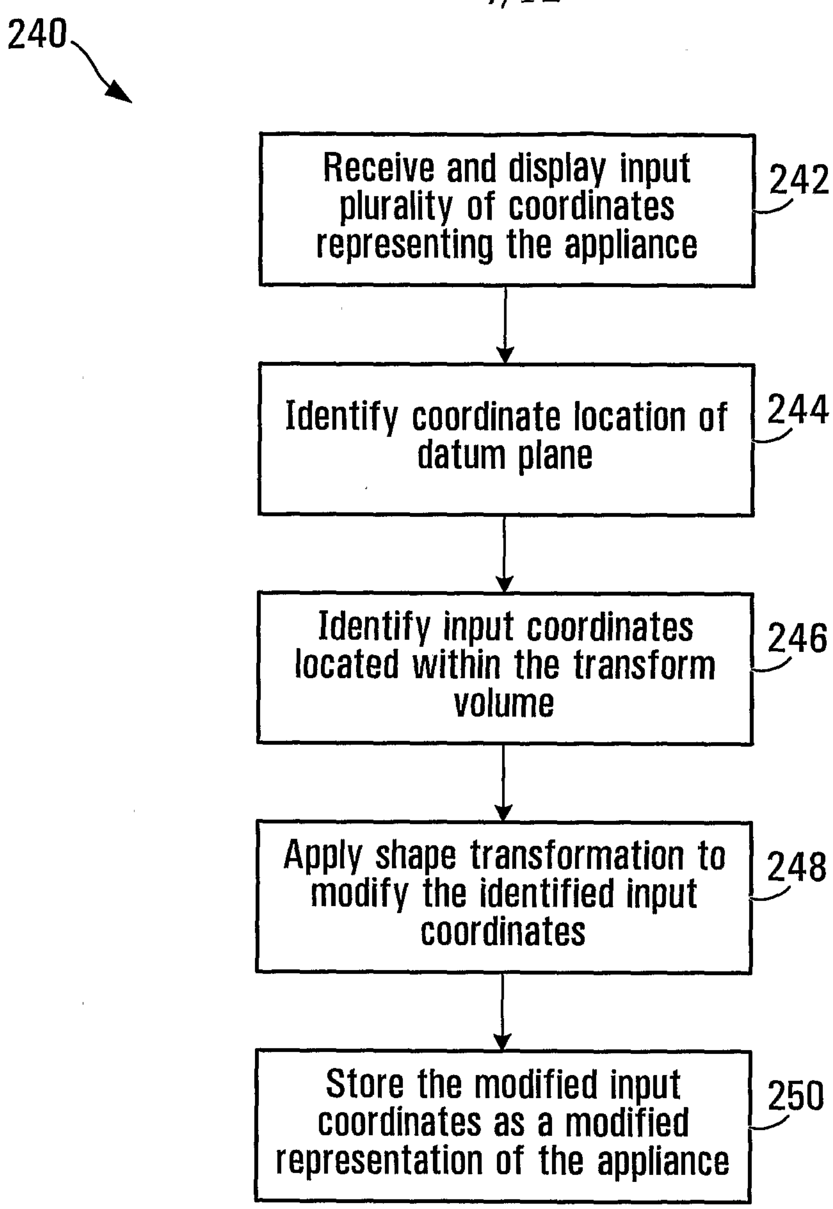
240
Receive and display input plurality of coordinates representing the appliance
242
Identify coordinate location of datum plane
244
Identify input coordinates located within the transform volume
246
Apply shape transformation to modify the identified input coordinates
248
Store the modified input coordinates as a modified representation of the appliance
250

FIG. 4

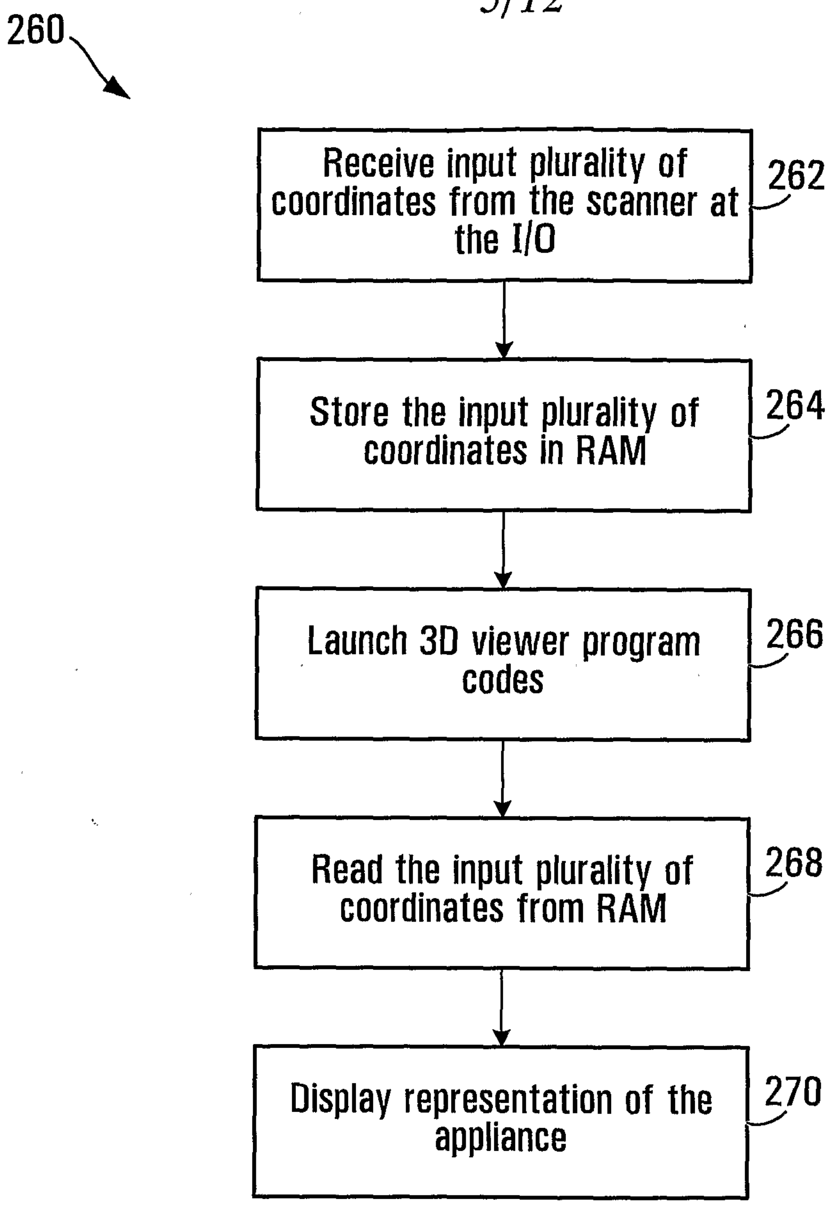
260
Receive input plurality of coordinates from the scanner at the I/O
262
Store the input plurality of coordinates in RAM
264
Launch 3D viewer program codes
266
Read the input plurality of coordinates from RAM
268
Display representation of the appliance
270

FIG. 5

6/12

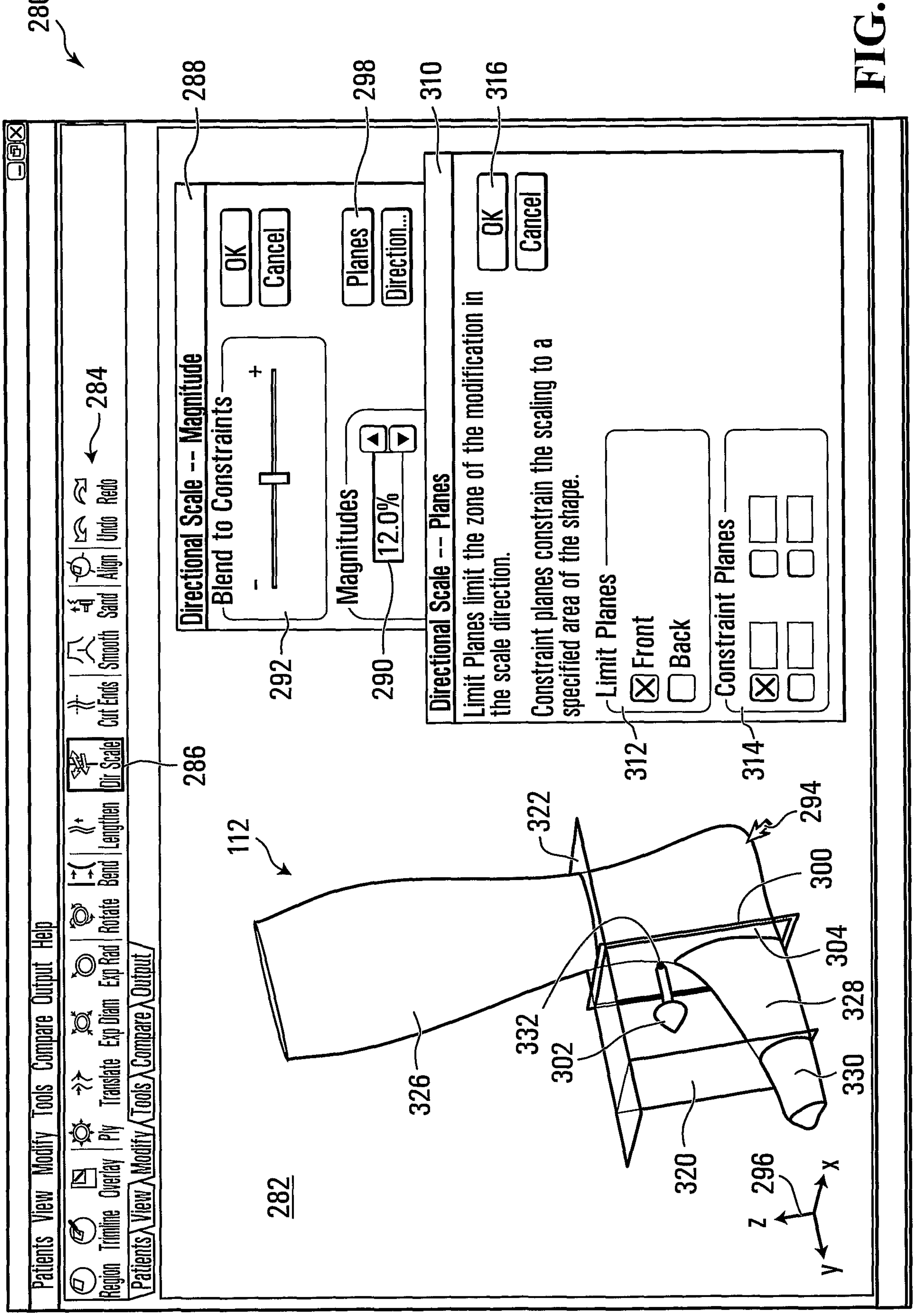
280
Patients View Modify Tools Compare Output Help
Region Trimline Overlay Ply Translate Exp Diam Exp Rad Rotate Bend Lengthen Dir Scale Cut Ends Smooth Sand Align Undo Redo
284
Patients View Modify Tools Compare Output
286
288
Directional Scale -- Magnitude
Blend to Constraints
- +
OK
Cancel
Magnitudes
12.0%
Planes
Direction...
292
290
298
310
316
Directional Scale -- Planes
Limit Planes limit the zone of the modification in the scale direction.
Constraint planes constrain the scaling to a specified area of the shape.
OK
Cancel
Limit Planes
Front
Back
Constraint Planes
312
314
112
282
322
294
300
304
328
330
332
302
326
320
296
z
x
y

FIG. 6

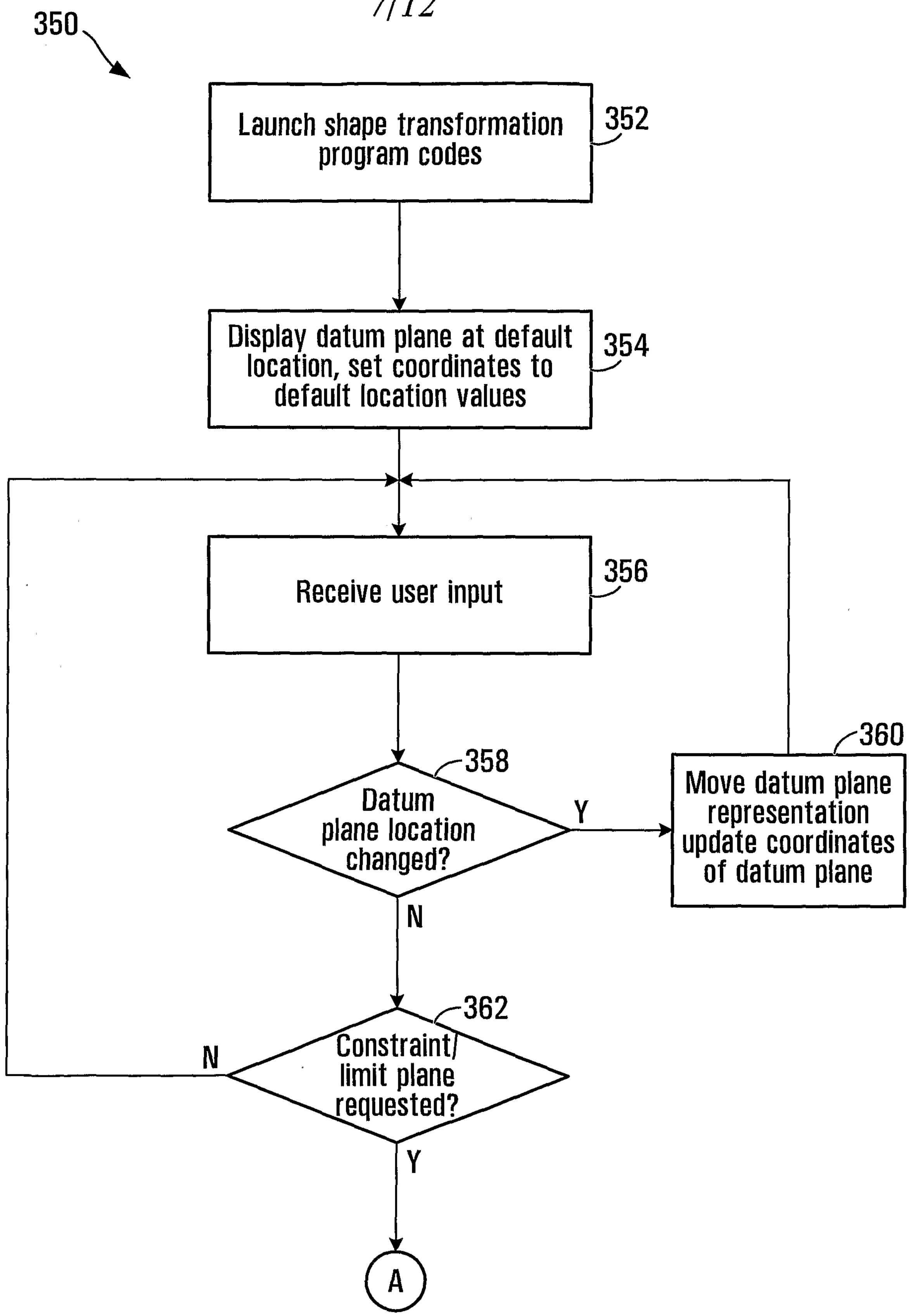
350
Launch shape transformation program codes
352
Display datum plane at default location, set coordinates to default location values
354
Receive user input
356
Datum plane location changed?
358
Y
N
Move datum plane representation update coordinates of datum plane
360
Constraint/ limit plane requested?
362
N
Y
A

FIG. 7A

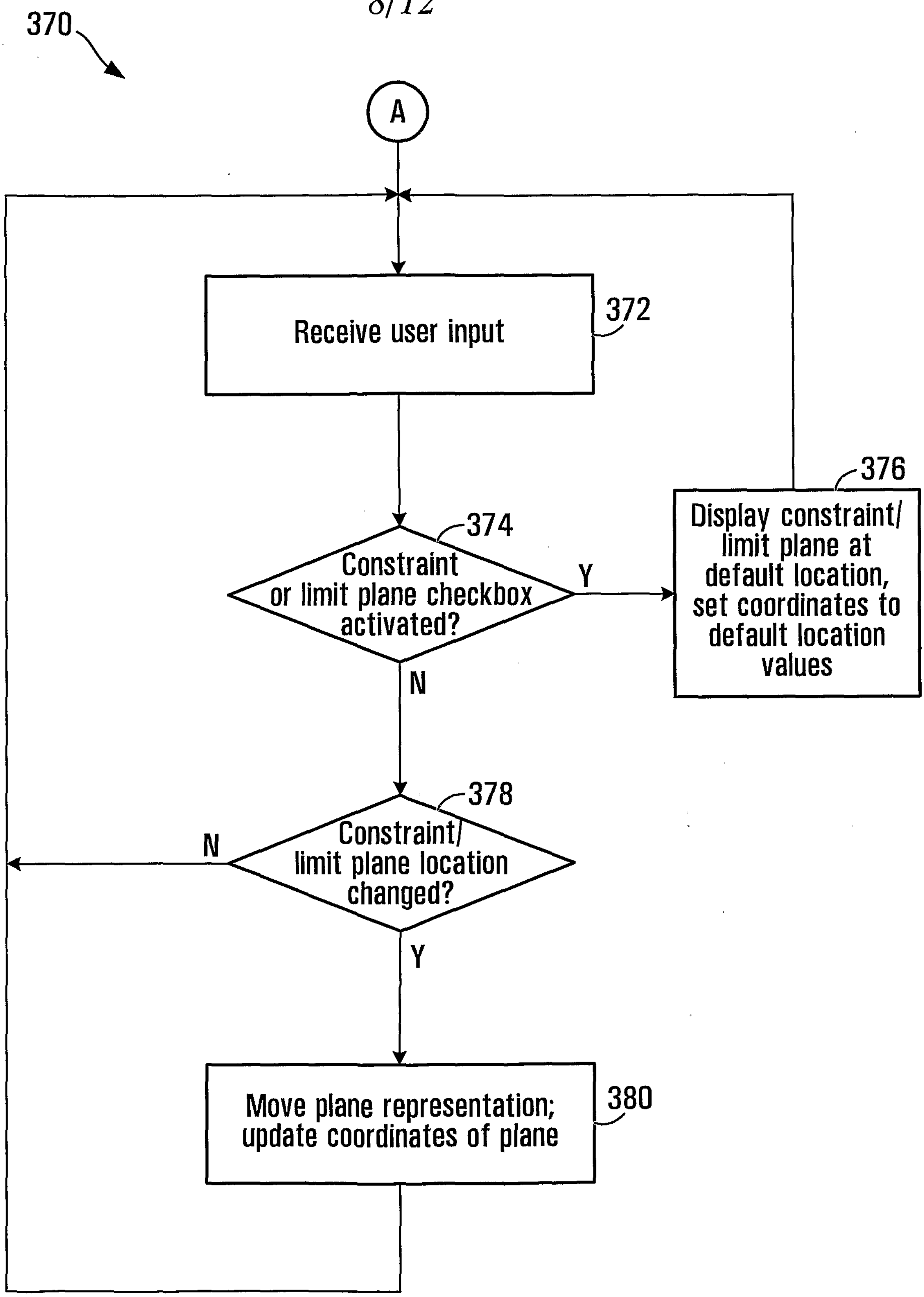
370
A
Receive user input
372
374
Constraint or limit plane checkbox activated?
Y
376
Display constraint/ limit plane at default location, set coordinates to default location values
N
378
Constraint/ limit plane location changed?
N
Y
Move plane representation; update coordinates of plane
380

FIG. 7B

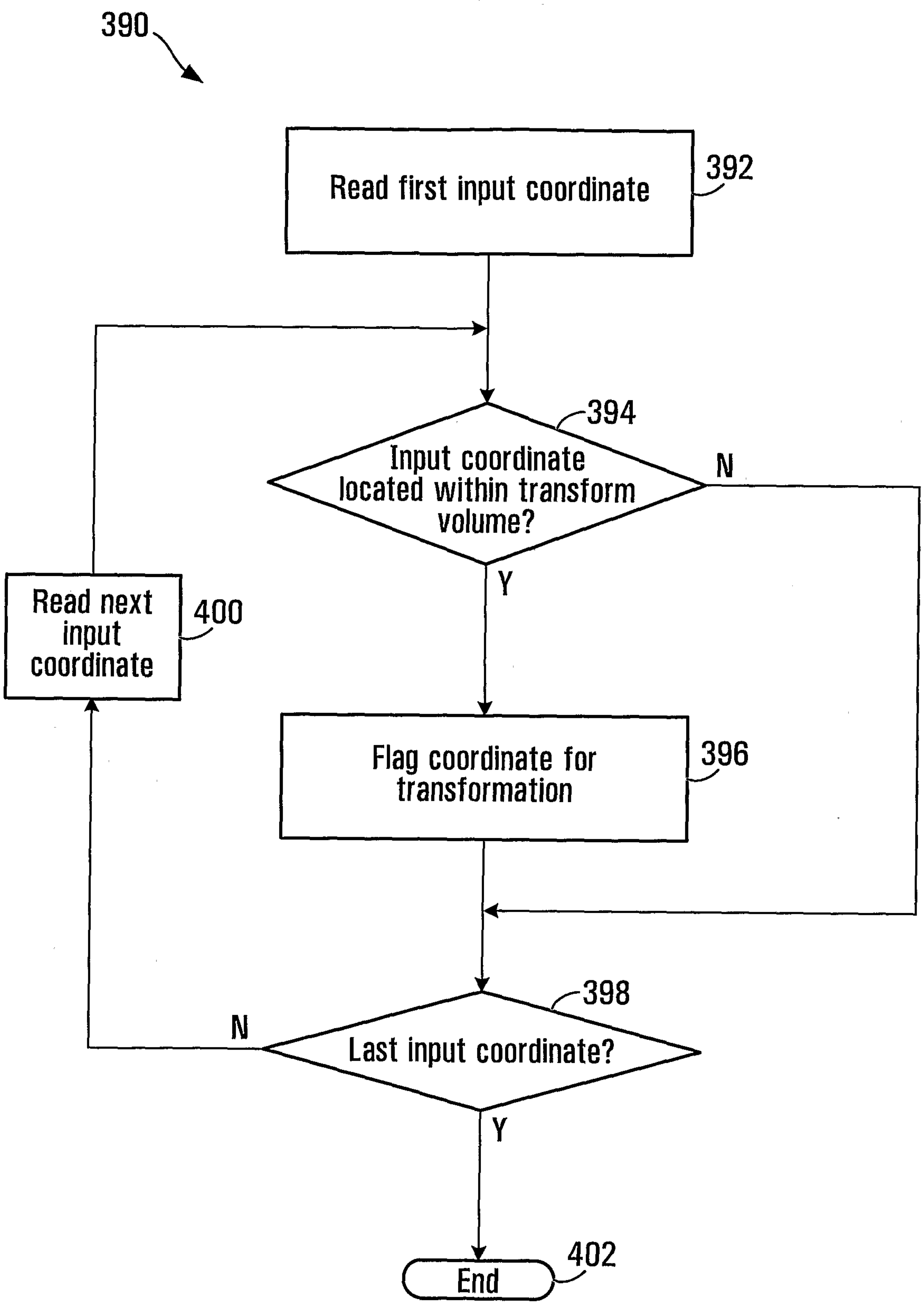
390
Read first input coordinate
392
394
Input coordinate located within transform volume?
N
Y
Read next input coordinate
400
Flag coordinate for transformation
396
398
N
Last input coordinate?
Y
End
402

FIG. 8

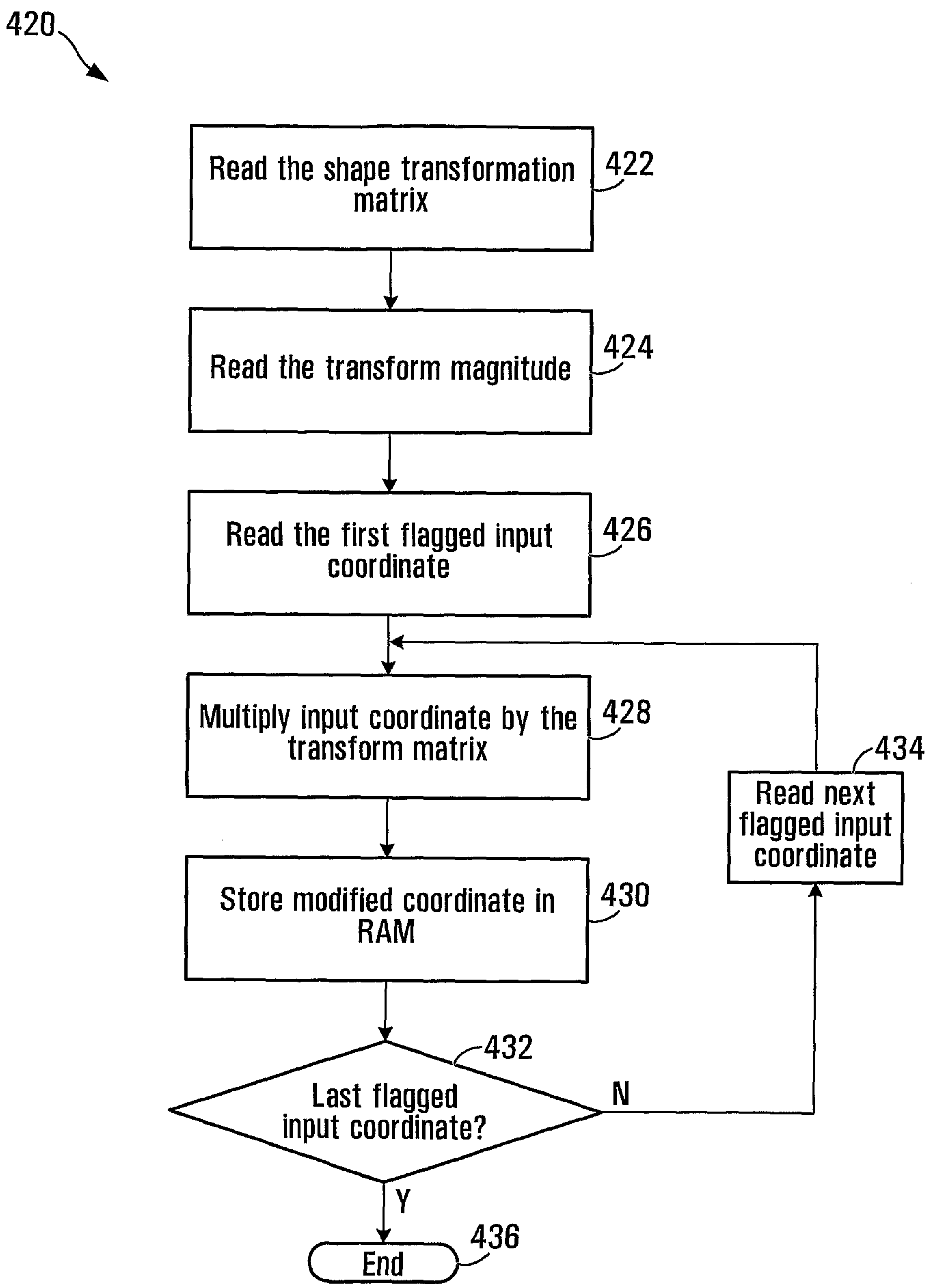
420
Read the shape transformation matrix
422
Read the transform magnitude
424
Read the first flagged input coordinate
426
Multiply input coordinate by the transform matrix
428
Store modified coordinate in RAM
430
Last flagged input coordinate?
432
N
Read next flagged input coordinate
434
Y
End
436

FIG. 9

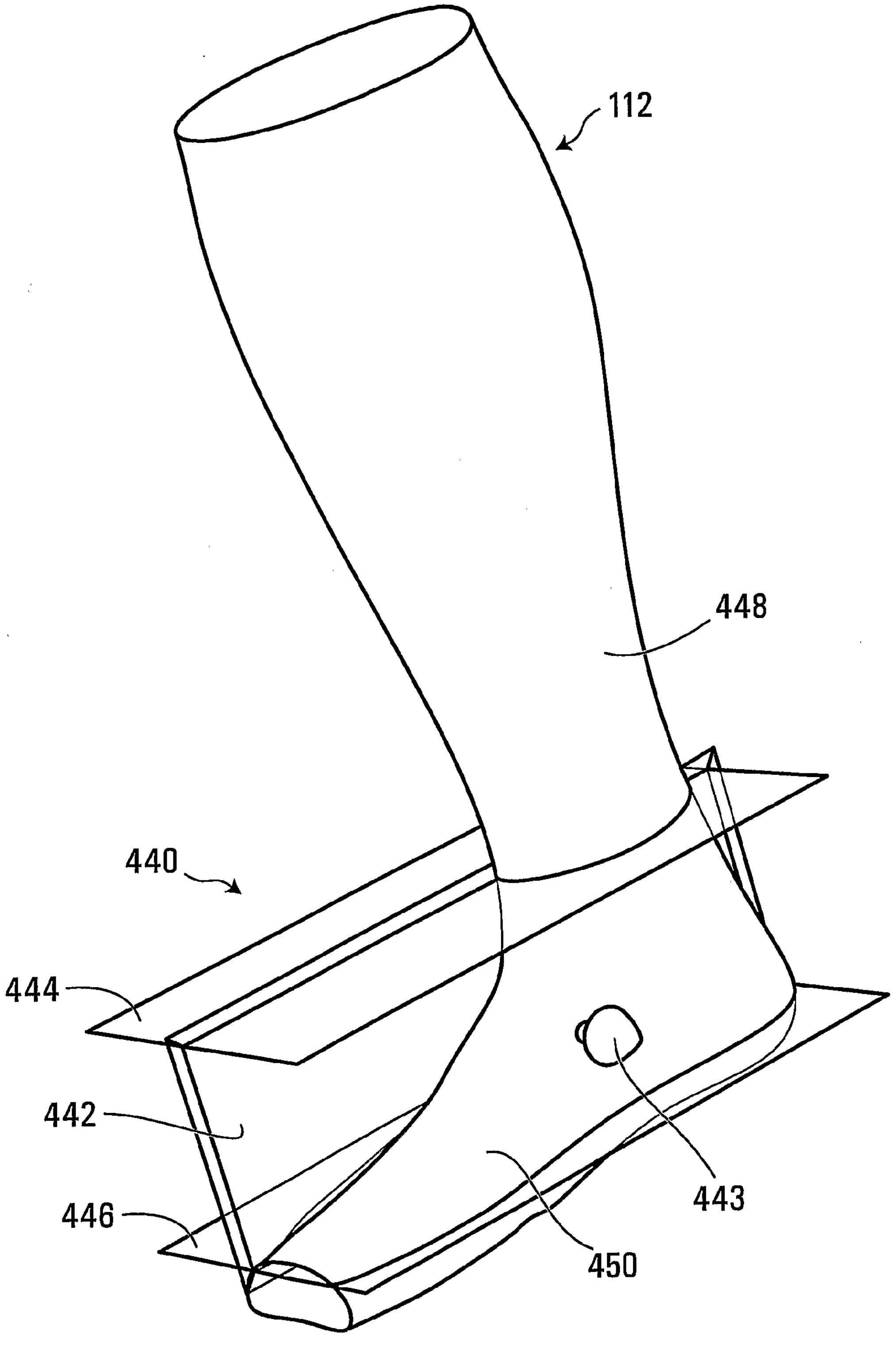

FIG. 10

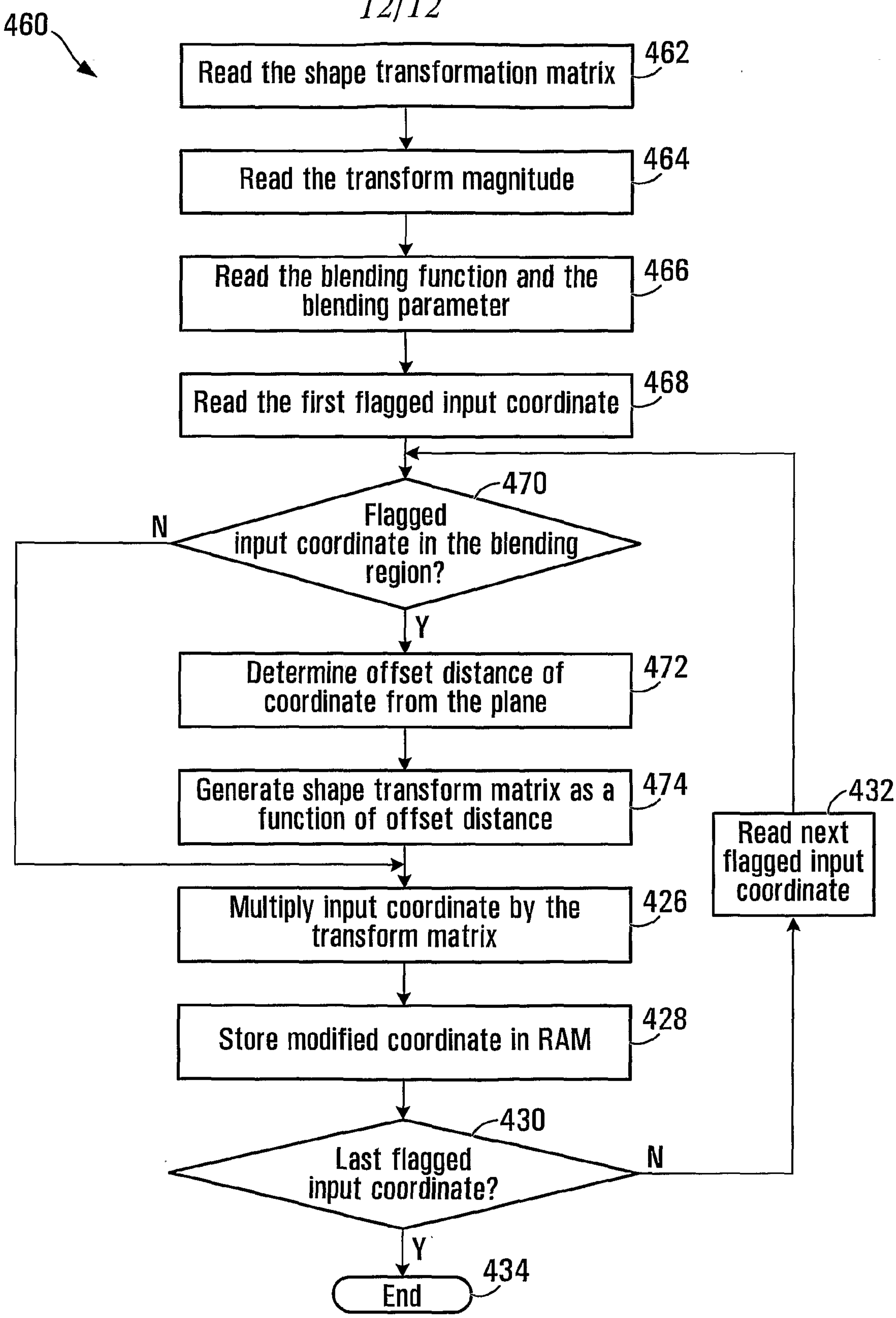
460
Read the shape transformation matrix
462
Read the transform magnitude
464
Read the blending function and the blending parameter
466
Read the first flagged input coordinate
468
Flagged input coordinate in the blending region?
470
N
Y
Determine offset distance of coordinate from the plane
472
Generate shape transform matrix as a function of offset distance
474
Multiply input coordinate by the transform matrix
426
Store modified coordinate in RAM
428
Last flagged input coordinate?
430
N
Y
Read next flagged input coordinate
432
End
434

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2007/001884

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***G06T 17/40*** (2006.01) , ***G06T 3/40*** (2006.01) , ***G06T 3/60*** (2006.01) , *A61F 5/01* (2006.01)
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)
IPC: ***G06T 17/40*** (2006.01) , ***G06T 3/40*** (2006.01) , ***G06T 3/60*** (2006.01) , *A61F 5/01* (2006.01)
in combination with keywords

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Canadian Patent Database, USPTO, Questel•Orbit QPAT, Delphion, IEEE-online, Google
Keywords: shape, transform, prosthetics or orthotic, plane, coordinate, constraint

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US4436684 (WHITE) 13 March 1984 (13-03-1984) * fig. 9A, 9B; col. 4, line 33 to col. 5, line 26; col. 11, line 60 to col. 12, line 37; col. 14, line 62 to col. 15, line 31; col. 15, line 60 to col. 17, line 59*	1, 18, 19, 36, 37, 55, 56
A, L	ANONYMOUS: “CANFIT-PLUSTM P&O Design”, posted on the Internet on 15 October 2006 and accessed 19 June 2008 at http://web.archive.org/web/20061015183514/www.vorum.com/P&O_System/prod_P&OSystem_P&O_Design.asp?pageID=28 * whole article *	1, 18, 19, 36, 37, 55, 56
A	HE et al.: "A PC-based ultrasound scanning system for imaging a residual limb" Proceedings of the 16th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 1994. Baltimore, MD, USA, 3-6 Nov 1994, pages 480-481, vol. 1, ISBN: 0-7803-2050-6 * page 481, section IV *	1, 19, 37, 55, 56
A	CA2405738 A1 (SHIMADA et al.) 18 Oct. 2001 (18-10-2001) * abstract, page 17, line 8 to page 18, line 4; page 18, line 18 to page 22, line 29 *	1, 19, 37, 55, 56

[ ] 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 application or patent 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
18 June 2008 (18-06-2008)	11 July 2008 (11-07-2008)

Name and mailing address of the ISA/CA	Authorized officer
Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Corneliu Remes 819- 934-2675

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2007/001884

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US4436684	13-03-1984	CA1201512 A1	04-03-1986
		DE3366423D D1	30-10-1986
		EP0097001 A1	28-12-1983
		JP1889523C C	07-12-1994
CA2405738	18-10-2001	AU3086402 A	21-05-2002
		AU5321601 A	23-10-2001
		CA2426715 A1	16-05-2002
		EP1303841 A2	23-04-2003
		EP1346199 A2	24-09-2003
		JP2003530177T T	14-10-2003
		US6701174 B1	02-03-2004
		US6711432 B1	23-03-2004
		US2004039259 A1	26-02-2004
		US2004068187 A1	08-04-2004
		WO0178015 A2	18-10-2001
		WO0237935 A2	16-05-2002