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(54) **Title**: METHOD AND APPARATUS FOR APPLYING A ROTATIONAL TRANSFORM TO A PORTION OF A THREE-DIMENSIONAL REPRESENTATION OF AN APPLIANCE FOR A LIVING BODY

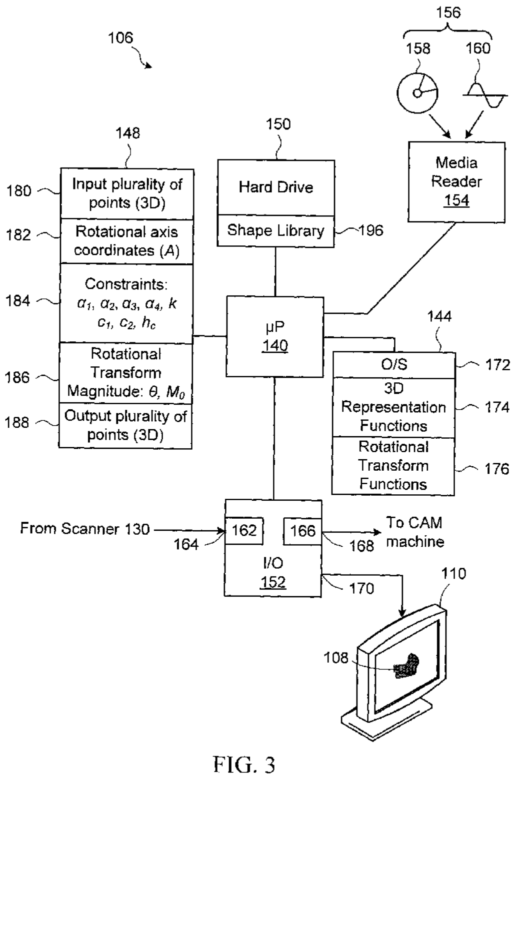

FIG. 3

(57) Abstract: A method and apparatus for applying a rotational transform to 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 stored in a processor circuit memory, the input plurality of coordinates representing a general shape of the appliance. The method involves receiving operator input identifying a coordinate location of a rotational axis about which the rotational transform is to be applied, receiving operator input of at least one constraint defining an extent of a transform volume within which the rotational transform is to be applied to the representation of the appliance, and receiving operator input of a rotational transform magnitude. The method also involves applying the rotational transform to the portion of the representation of the appliance within the transform volume to produce an output plurality of coordinates representing a modified shape of the appliance such that the general shape of portions of the appliance outside the transform volume remain un-modified by the rotational transform, and storing the output plurality of coordinates in the processor circuit memory.

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METHOD AND APPARATUS FOR APPLYING A ROTATIONAL TRANSFORM TO A PORTION OF A THREE-DIMENSIONAL REPRESENTATION OF AN APPLIANCE FOR A LIVING BODY

BACKGROUND OF THE INVENTION

1. Field of Invention

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

2. Description of Related Art

Prostheses, orthoses, and other support appliances 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 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 an appliance, or to produce a mold for making an 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. Other appliances such as supporting seats or standing shells for supporting the body of a person having limited mobility may also be produced from modified representations of body parts.

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 coordinates of the surface of the body part, which may be used as input coordinates to a computer for producing a preliminary three-dimensional representation of the appliance. In cases where scanned input coordinates are available for the specific patient for whom the appliance is to be produced, it is common to make certain modifications to the scanned coordinates to provide compression and/or relief such that the final appliance provides the required support where needed while being sufficiently comfortable for the patient. In other cases, the preliminary three-dimensional representation of the appliance may be provided from a library of body parts, which may require modifications in size and shape to provide the required support and comfort for the patient.

There remains a need for methods and apparatus for modifying a set of input coordinates representing a preliminary shape of an appliance to produce a modified set of coordinates representing a final shape of the appliance.

SUMMARY OF THE INVENTION

In accordance with one aspect of the invention there is provided a method for applying a rotational transform to a portion of a three-dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates stored in a processor circuit memory, the input plurality of coordinates representing a general shape of the appliance. The method involves receiving operator input identifying a coordinate location of a rotational axis about which the rotational transform is to be applied, receiving operator input of at least one constraint defining an extent of a transform volume within which the rotational transform is to be applied to the representation of the appliance, and receiving operator input of a rotational transform magnitude. The method also involves applying the rotational transform to the portion of the representation of the appliance within the transform volume to produce an output plurality of coordinates representing a modified shape of the appliance such that the general shape of portions of the appliance outside the transform volume remain un-modified by the rotational transform, and storing the output plurality of coordinates in the processor circuit memory.

The method may involve generating a set of instructions operable to control a computer aided manufacturing machine to produce one of the appliance and a mold for producing the appliance in accordance with the output plurality of coordinates.

The method may involve generating display signals operable to cause a representation of the output plurality of coordinates to be displayed on a display associate with the processor circuit.

Receiving the operator input of the at least one constraint may involve receiving operator input of at least one axial constraint limiting an extent of the transform volume in a direction along the rotational axis.

Receiving the operator input defining the at least one axial constraint may involve receiving operator input defining at least one constraint plane oriented orthogonal to the rotational axis and intersecting the appliance representation.

Receiving the operator input defining the at least one axial constraint may involve receiving operator input defining first and second spaced apart axial constraints along the rotational axis, the first and second axial constraints limiting an extent of the transform volume to between the first and second axial constraints.

The method may involve identifying an axial blending region extending into the transform volume from the at least one axial constraint, and applying the rotational transform may involve reducing a magnitude of the rotational transform within the axial blending region to cause continuity of shape between modified portions of the representation of the appliance within the transform volume and un-modified portions of the representation of the appliance outside the transform volume.

Reducing the magnitude of the rotational transform may involve applying a rotational transform having substantially zero magnitude at the axial constraint, and a magnitude that progressively increases with distance away from the at least one axial constraint to reach a full rotational transform magnitude beyond the axial blending region.

Identifying the axial blending region may involve receiving operator input of a distance defining an extent of the blending region into the transform volume.

Receiving the operator input of the at least one constraint may involve receiving operator input of first and second rotational constraints with respect to the rotational axis, the first and second rotational constraints defining an angular extent of the transform volume about the rotational axis.

Applying the rotational transform to the portion of the three-dimensional representation of the appliance within the transform volume may involve identifying first and second rotational blending regions extending from the first and second rotational constraints into the transform volume, and applying the rotational transform may involve reducing a magnitude of the rotational transform within the first and second rotational blending regions respectively to cause continuity of shape between modified portions of the representation of the appliance within the transform volume and un-modified portions of the representation of the appliance outside the transform volume.

Reducing the magnitude of the rotational transform may involve applying a rotational transform having substantially zero magnitude at the first and second rotational constraints, and a magnitude that progressively increases with rotational displacement into the transform volume to reach a full rotational transform magnitude beyond the first and second rotational blending regions respectively.

Identifying the first and second rotational blending regions may involve receiving operator input defining a rotational extent of the first and second rotational blending regions into the transform volume.

Identifying the first and second rotational blending regions may involve receiving operator input of a no-blending zone located between the first and second rotational constraints, the no-blending zone defining an angular extent of the transform volume about the rotational axis within which a full magnitude of the rotational transform is to be to be applied, and where the first and second rotational blending regions respectively include portions of the transform volume outside the no-blending zone.

The method may involve receiving operator input of a desired rotational magnitude and direction of the rotational transform to be applied to the portion of the three-dimensional representation of the appliance within the transform volume.

The method may involve defining a reference plane oriented orthogonal to the rotational axis and intersecting the appliance representation, displaying a two-dimensional view of an intersection between the three dimensional representation of the appliance and the reference plane, and receiving the operator input of the desired magnitude and direction of the rotational transform to be applied may involve receiving an operator selection of a reference point on the reference plane and receiving operator input of a desired rotational displacement of the reference point.

The method may involve displaying a modified shape of the intersection in the two-dimensional view.

Applying the rotational transform may involve for each input coordinate in the input plurality of coordinates determining an angular displacement to be applied to the input coordinate, and generating a rotational transformation matrix for the input coordinate, the rotational transform matrix including elements operable to transform the input coordinate into an output coordinate that may be angularly displaced from the input coordinate by the angular displacement about the rotational axis.

The input plurality of coordinates may be defined in a first Cartesian coordinate system and the method may further involve generating a modeling matrix having elements operable to transform input coordinates between the first coordinate system and a second Cartesian coordinate system, the second coordinate system having an origin located on the rotational axis, a first axis aligned with the rotational axis, and second and third axes orthogonal to the rotational axis. Determining the angular displacement may involve determining a corresponding coordinate of the input coordinate in the second coordinate system, and determining an angular displacement of each the corresponding coordinate within a plane defined by the second and third axes of the second coordinate system.

Receiving operator input identifying the coordinate location of the rotational axis may involve receiving operator input defining coordinates of a three-dimensional line representing a location of the rotational axis with respect to the appliance representation, a location of a reference plane intersecting the appliance representation and oriented orthogonal to the three-dimensional line, and a location of an origin point on the reference plane through which the rotational axis passes.

The method may involve displaying a three-dimensional representation of the appliance, the reference plane, and the three-dimensional line and receiving the operator input may involve receiving pointer signals from a pointing device in communication with the processor circuit, the pointing signals being operable to define desired changes to the coordinates of at least one of the three-dimensional line, the location of the reference plane, and the location of the origin point on the reference plane with respect to the appliance.

The method may involve displaying a two-dimensional view of the intersection of the general shape of the appliance with the reference plane and receiving the operator input may involve receiving pointer signals from the pointing device, the pointing signals being operable to define desired changes to the origin point on the reference plane.

Applying the rotational transform to the portion of the three-dimensional representation of the appliance within the transform volume to produce an output plurality of coordinates may involve producing modified coordinates representing the modified shape of the appliance within the transform volume, and re-sampling the modified coordinates and the un-modified coordinates outside the transform volume to produce the output plurality of coordinates representing the modified appliance representation.

In accordance with another aspect of the invention there is provided an apparatus for applying a rotational transform to a portion of a three-dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates, the input plurality of coordinates representing a general shape of the appliance. The apparatus includes a processor circuit operably configured to receive operator input identifying a coordinate location of a rotational axis about which the rotational transform is to be applied, to receive operator input of at least one constraint defining an extent of a transform volume within which the rotational transform is to be applied to the representation of the appliance, and to receive operator input of a rotational transform magnitude. The processor circuit is also operably configured to apply the rotational transform to the portion of the representation of the appliance within the transform volume to produce an output plurality of coordinates representing a modified shape of the appliance such that the general shape of portions of the appliance outside the transform volume remain un-modified by the rotational transform, and to store the output plurality of coordinates in a memory of the processor circuit.

The processor circuit may be operably configured to generate a set of instructions operable to control a computer aided manufacturing machine to produce one of the appliance and a mold for producing the appliance in accordance with the output plurality of coordinates.

The processor circuit may be operably configured to generate display signals operable to cause a representation of the output plurality of coordinates to be displayed.

The processor circuit may be operably configured to receive the operator input of the at least one constraint by receiving operator input of at least one axial constraint limiting an extent of the transform volume in a direction along the rotational axis.

The processor circuit may be operably configured to receive the operator input defining the at least one axial constraint by receiving operator input defining at least one constraint plane oriented orthogonal to the rotational axis and intersecting the appliance representation.

The processor circuit may be operably configured to receive the operator input defining the at least one axial constraint by receiving operator input defining first and second spaced apart axial constraints along the rotational axis, the first and second axial constraints limiting an extent of the transform volume to between the first and second axial constraints.

The processor circuit may be operably configured to identify an axial blending region extending into the transform volume from the at least one axial constraint, and the processor circuit may be operably configured to apply the rotational transform by reducing a magnitude of the rotational transform within the axial blending region to cause continuity of shape between modified portions of the representation of the appliance within the transform volume and un-modified portions of the representation of the appliance outside the transform volume.

The processor circuit may be operably configured to reduce the magnitude of the rotational transform by applying a rotational transform having substantially zero magnitude at the axial constraint, and a magnitude that progressively increases with distance away from the at least one axial constraint to reach a full rotational transform magnitude beyond the axial blending region.

The processor circuit may be operably configured to identify the axial blending region by receiving operator input of a distance defining an extent of the blending region into the transform volume.

The processor circuit may be operably configured to receive the operator input of the at least one constraint by receiving operator input of first and second rotational constraints with respect to the rotational axis, the first and second rotational constraints defining an angular extent of the transform volume about the rotational axis.

The processor circuit may be operably configured to apply the rotational transform to the portion of the three-dimensional representation of the appliance within the transform volume by identifying first and second rotational blending regions extending from the first and second rotational constraints into the transform volume, and the processor circuit may be operably configured to apply the rotational transform by reducing a magnitude of the rotational transform within the first and second rotational blending regions respectively to cause continuity of shape between modified portions of the representation of the appliance within the transform volume and un-modified portions of the representation of the appliance outside the transform volume.

The processor circuit may be operably configured to reduce the magnitude of the rotational transform by applying a rotational transform having substantially zero magnitude at the first and second rotational constraints, and a magnitude that progressively increases with rotational displacement into the transform volume to reach a full rotational transform magnitude beyond the first and second rotational blending regions respectively.

The processor circuit may be operably configured to identify the first and second rotational blending regions by receiving operator input defining a rotational extent of the first and second rotational blending regions into the transform volume.

The processor circuit may be operably configured to identify the first and second rotational blending regions by receiving operator input of a no-blending zone located between the first and second rotational constraints, the no-blending zone defining an angular extent of the transform volume about the rotational axis within which a full magnitude of the rotational transform is to be applied, and the first and second rotational blending regions respectively may include portions of the transform volume outside the no-blending zone.

The processor circuit may be operably configured to receive operator input of a desired rotational magnitude and direction of the rotational transform to be applied to the portion of the three-dimensional representation of the appliance within the transform volume.

The processor circuit may be operably configured to define a reference plane oriented orthogonal to the rotational axis and intersecting the appliance representation, to display a two-dimensional view of an intersection between the three dimensional representation of the appliance and the reference plane, and the processor circuit may be operably configured to receive the operator input of the desired magnitude and direction of the rotational transform to be applied by receiving an operator selection of a reference point on the reference plane, and receiving operator input of a desired rotational displacement of the reference point.

The processor circuit may be operably configured to display a modified shape of the intersection in the two-dimensional view.

The processor circuit may be operably configured to apply the rotational transform by determining an angular displacement to be applied to each input coordinate in the input plurality of coordinates, and generating a rotational transformation matrix for the input coordinate, the rotational transform matrix including elements operable to transform the input coordinate into an output coordinate that is angularly displaced from the input coordinate by the angular displacement about the rotational axis.

The input plurality of coordinates may be defined in a first Cartesian coordinate system and the processor circuit may be operably configured to generate a modeling matrix having elements operable to transform input coordinates between the first coordinate system and a second Cartesian coordinate system, the second coordinate system having an origin located on the rotational axis, a first axis aligned with the rotational axis, and second and third axes orthogonal to the rotational axis, and the processor circuit may be operably configured to determine the angular displacement by determining a corresponding coordinate of the input coordinate in the second coordinate system, and determining an angular displacement of each the corresponding coordinate within a plane defined by the second and third axes of the second coordinate system.

The processor circuit may be operably configured to receive operator input identifying the coordinate location of the rotational axis by receiving operator input defining coordinates of a three-dimensional line representing a location of the rotational axis with respect to the appliance representation, a location of a reference plane intersecting the appliance representation and oriented orthogonal to the three-dimensional line, and a location of an origin point on the reference plane through which the rotational axis passes.

The processor circuit may be operably configured to display a three-dimensional representation of the appliance, the reference plane, and the three-dimensional line and the processor circuit may be operably configured to receive the operator input by receiving pointer signals from a pointing device in communication with the processor circuit, the pointing signals being operable to define desired changes to the coordinates of at least one of the three-dimensional line, the location of the reference plane, and the location of the origin point on the reference plane with respect to the appliance.

The processor circuit may be operably configured to display a two-dimensional view of the intersection of the general shape of the appliance with the reference plane and the processor circuit may be operably configured to receive the operator input by receiving pointer signals from the pointing device, the pointing signals being operable to define desired changes to the origin point on the reference plane.

The processor circuit may be operably configured to apply the rotational transform to the portion of the three-dimensional representation of the appliance within the transform volume to produce an output plurality of coordinates by producing modified coordinates representing the modified shape of the appliance within the transform volume, and re-sampling the modified coordinates and the un-modified coordinates outside the transform volume to produce the output plurality of coordinates representing the modified appliance representation.

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 rotational transform to a portion of a three-dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates stored in a processor circuit memory, the input plurality of coordinates representing a general shape of the appliance. The codes direct the processor circuit to receive operator input identifying a coordinate location of a rotational axis about which the rotational transform is to be applied, and to receive operator input of at least one constraint defining an extent of a transform volume within which the rotational transform is to be applied to the representation of the appliance, and to receive operator input of a rotational transform magnitude. The codes also direct the processor circuit to apply the rotational transform to the portion of the representation of the appliance within the transform volume to produce an output plurality of coordinates representing a modified shape of the appliance such that the general shape of portions of the appliance outside the transform volume remain un-modified by the rotational transform, and to store the output plurality of coordinates in a memory of the processor circuit.

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 rotational transform to a portion of a three-dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates stored in a processor circuit memory, the input plurality of coordinates representing a general shape of the appliance. The codes direct the processor circuit to receive operator input identifying a coordinate location of a rotational axis about which the rotational transform is to be applied, and to receive operator input of at least one constraint defining an extent of a transform volume within which the rotational transform is to be applied to the representation of the appliance, and to receive operator input of a rotational transform magnitude. The codes also direct the processor circuit to apply the rotational transform to the portion of the representation of the appliance within the transform volume to produce an output plurality of coordinates representing a modified shape of the appliance such that the general shape of portions of the appliance outside the transform volume remain un-modified by the rotational transform, and to store the output plurality of coordinates in a memory of the processor circuit.

In accordance with another aspect of the invention there is provided an apparatus for applying a rotational transform to a portion of a three-dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates stored in a processor circuit memory, the input plurality of coordinates representing a general shape of the appliance. The apparatus includes provisions for receiving operator input identifying a coordinate location of a rotational axis about which the rotational transform is to be applied, provisions for receiving operator input of at least one constraint defining an extent of a transform volume within which the rotational transform is to be applied to the representation of the appliance, and provisions for receiving operator input of a rotational transform magnitude. The apparatus also includes provisions for applying the rotational transform to the portion of the representation of the appliance within the transform volume to produce an output plurality of coordinates representing a modified shape of the appliance such that the general shape of portions of the appliance outside the transform volume remain un-modified by the rotational transform, and provisions for storing the output plurality of coordinates in the processor circuit memory.

The apparatus may include provisions for generating a set of instructions operable to control a computer aided manufacturing machine to produce one of the appliance and a mold for producing the appliance in accordance with the output plurality of coordinates.

The apparatus may include provisions for generating display signals operable to cause a representation of the output plurality of coordinates to be displayed on a display associate with the processor circuit.

The provisions for receiving the operator input of the at least one constraint may include provisions for receiving operator input of at least one axial constraint limiting an extent of the transform volume in a direction along the rotational axis.

The provisions for receiving the operator input defining the at least one axial constraint may include provisions for receiving operator input defining at least one constraint plane oriented orthogonal to the rotational axis and intersecting the appliance representation.

The provisions for receiving the operator input defining the at least one axial constraint may include provisions for receiving operator input defining first and second spaced apart axial constraints along the rotational axis, the first and second axial constraints limiting an extent of the transform volume to between the first and second axial constraints.

The apparatus may include provisions for identifying an axial blending region extending into the transform volume from the at least one axial constraint, and the provisions for applying the rotational transform may include provisions for reducing a magnitude of the rotational transform within the axial blending region to cause continuity of shape between modified portions of the representation of the appliance within the transform volume and un-modified portions of the representation of the appliance outside the transform volume.

The provisions for reducing the magnitude of the rotational transform may include provisions for applying a rotational transform having substantially zero magnitude at the axial constraint, and a magnitude that progressively increases with distance away from the at least one axial constraint to reach a full rotational transform magnitude beyond the axial blending region.

The provisions for identifying the axial blending region may include provisions for receiving operator input of a distance defining an extent of the blending region into the transform volume.

The provisions for receiving the operator input of the at least one constraint may include provisions for receiving operator input of first and second rotational constraints with respect to the rotational axis, the first and second rotational constraints defining an angular extent of the transform volume about the rotational axis.

The provisions for applying the rotational transform to the portion of the three-dimensional representation of the appliance within the transform volume may include provisions for identifying first and second rotational blending regions extending from the first and second rotational constraints into the transform volume, and the provisions for applying the rotational transform may include provisions for reducing a magnitude of the rotational transform within the first and second rotational blending regions respectively to cause continuity of shape between modified portions of the representation of the appliance within the transform volume and un-modified portions of the representation of the appliance outside the transform volume.

The provisions for reducing the magnitude of the rotational transform may include provisions for applying a rotational transform having substantially zero magnitude at the first and second rotational constraints, and a magnitude that progressively increases with rotational displacement into the transform volume to reach a full rotational transform magnitude beyond the first and second rotational blending regions respectively.

The provisions for identifying the first and second rotational blending regions may include provisions for receiving operator input defining a rotational extent of the first and second rotational blending regions into the transform volume.

The provisions for identifying the first and second rotational blending regions may include provisions for receiving operator input of a no-blending zone located between the first and second rotational constraints, the no-blending zone defining an angular extent of the transform volume about the rotational axis within which a full magnitude of the rotational transform is to be applied, and the first and second rotational blending regions respectively may include portions of the transform volume outside the no-blending zone.

The apparatus may include provisions for receiving operator input of a desired rotational magnitude and direction of the rotational transform to be applied to the portion of the three-dimensional representation of the appliance within the transform volume.

The apparatus may include provisions for defining a reference plane oriented orthogonal to the rotational axis and intersecting the appliance representation, provisions for displaying a two-dimensional view of an intersection between the three dimensional representation of the appliance and the reference plane, wherein the provisions for receiving the operator input of the desired magnitude and direction of the rotational transform to be applied may include provisions for receiving an operator selection of a reference point on the reference plane, and provisions for receiving operator input of a desired rotational displacement of the reference point.

The apparatus may include provisions for displaying a modified shape of the intersection in the two-dimensional view.

The provisions for applying the rotational transform may include provisions for determining an angular displacement to be applied to each input coordinate in the input plurality of coordinates, and provisions for generating a rotational transformation matrix for the input coordinate, the rotational transform matrix including elements operable to transform the input coordinate into an output coordinate that may be angularly displaced from the input coordinate by the angular displacement about the rotational axis.

The input plurality of coordinates may be defined in a first Cartesian coordinate system and may further include provisions for generating a modeling matrix having elements operable to transform input coordinates between the first coordinate system and a second Cartesian coordinate system, the second coordinate system having an origin located on the rotational axis, a first axis aligned with the rotational axis, and second and third axes orthogonal to the rotational axis, and the provisions for determining the angular displacement may include provisions for determining a corresponding coordinate of the input coordinate in the second coordinate system, and provisions for determining an angular displacement of each the corresponding coordinate within a plane defined by the second and third axes of the second coordinate system.

The provisions for receiving operator input identifying the coordinate location of the rotational axis may include provisions for receiving operator input defining coordinates of a three-dimensional line representing a location of the rotational axis with respect to the appliance representation, a location of a reference plane intersecting the appliance representation and oriented orthogonal to the three-dimensional line, and a location of an origin point on the reference plane through which the rotational axis passes.

The apparatus may include provisions for displaying a three-dimensional representation of the appliance, the reference plane, and the three-dimensional line and the provisions for receiving the operator input may include provisions for receiving pointer signals from a pointing device in communication with the processor circuit, the pointing signals being operable to define desired changes to the coordinates of at least one of the three-dimensional line, the location of the reference plane, and the location of the origin point on the reference plane with respect to the appliance.

The apparatus may include provisions for displaying a two-dimensional view of the intersection of the general shape of the appliance with the reference plane and the provisions for receiving the operator input may include provisions for receiving pointer signals from the pointing device, the pointing signals being operable to define desired changes to the origin point on the reference plane.

The provisions for applying the rotational transform to the portion of the three-dimensional representation of the appliance within the transform volume to produce an output plurality of coordinates may include provisions for producing modified coordinates representing the modified shape of the appliance within the transform volume, and provisions for re-sampling the modified coordinates and the un-modified coordinates outside the transform volume to produce the output plurality of coordinates representing the modified appliance representation.

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 perspective view of a CAD\CAM system for producing an appliance for a living body in accordance with one embodiment of the invention;

Figure **2** is a perspective view of a scanner for receiving a signal encoded with the input plurality of coordinates representing a general shape of a part of a living body for use in the CAD/CAM system shown in Figure **1**;

Figure **3** is a processor circuit for implementing the CAD system shown in Figure **1**;

Figure **4** is a flowchart of blocks of code for directing the processor circuit shown in Figure **3** to apply a rotational transform to a portion of a three-dimensional representation of an appliance;

Figure **5** is an exemplary **3**D representation displayed by the processor circuit shown in Figure **3**;

Figure **6** is a screenshot of an operator interface for receiving input identifying a desired coordinate location of a rotational axis;

Figure **7** is a perspective view of a **3**D representation of an appliance;

Figure **8** is a further perspective view of a **3**D representation of an appliance;

Figure **9** and **10** are screenshots of an operator interface for receiving operator input of rotational and/or axial constraints;

Figure **11** is a graphical depiction of an angular mapping between initial angle and final angle;

Figure **12** is a flowchart of blocks of code for directing the processor circuit shown in Figure **3** to apply a rotational transform to the portion of the **3**D appliance representation;

Figure **13** is a screenshot of an appliance modification performed in accordance with a first example;

Figure **14** is a screenshot of the operator interface shown in Figure **9** for the appliance modification example shown in Figure **13**;

Figure **15** is a screenshot of an appliance modification performed in accordance with a second example; and

Figure **16** is a screenshot of the operator interface shown in Figure **9** for the appliance modification example shown in Figure **15**.

DETAILED DESCRIPTION

System overview

Referring to Figure **1**, a CAD\CAM system for producing an appliance for a living body is shown generally at **100**. The system **100** includes a computer aided design (CAD) apparatus **102** and a computer aided manufacturing (CAM) machine **104**.

The CAD apparatus **102** includes a processor circuit **106**, which is operably configured to apply a rotational transform to a portion of a three-dimensional representation **108** of an appliance for a living body. The three-dimensional representation **108** is defined by an input plurality of coordinates representing a general shape of the appliance to be produced from the representation **108**. The apparatus **102** also includes a display **110**, which is in communication with the processor circuit **106**. In the embodiment shown the apparatus **102** also includes a pointing device **112** having one or more actuator buttons (not shown) for receiving operator input from an operator of the apparatus. The apparatus **102** also includes a keyboard **114** for receiving alphanumeric input from the operator. The processor circuit **106** produces signals for causing the display **110** to display a representation of a surface of the appliance being produced. The representation **108** displayed on the display **110** provides interactive visual feedback during modification of the appliance by an operator in response to operator inputs received at the pointing device **112** and the keyboard **114**.

In general, producing an appliance for a patient involves receiving the input plurality of coordinates, which define a preliminary representation of the surface of the appliance. The preliminary representation of the appliance is then transformed through various modifications to the general shape of the appliance to produce a final appliance representation. Such modifications may include modifications to the shape of surfaces, such as compressions in areas of the body that tolerate pressure and/or relief in certain other areas of the body that are sensitive to pressure, thus providing a comfortably fitting appliance for the patient. The effects of the modifications on the general shape of the appliance displayed on the display **110** to facilitate review of the modified shape prior to production of the final appliance.

In this embodiment, the CAM machine **104** includes a controller **116** and a machine tool portion **118** for machining the appliance. The controller **116** is in communication with the CAD apparatus **102** for receiving a signal encoded with data representing the modified appliance to be produced. The controller **116** transforms the data into carving instructions operable to control the CAM machine **104** to produce a machined appliance **120**. In this embodiment the machined appliance **120** is a mold which is subsequently used to produce a final appliance by molding a thermoplastic or other material over the mold. However in other embodiments final appliance may be machined directly by the CAM machine **104**, without the need to produce a mold.

In other embodiments the CAD apparatus **102** may be operably configured to produce an output file including carving instructions for controlling the CAM machine **104**. The output file may be transferred to the CAM machine **104** through a communication link or a computer readable medium such as a CD-ROM disk or flash drive, for example.

Referring to Figure **2**, in one embodiment the CAD apparatus **102** is in communication with a scanner **130** for receiving a signal encoded with the input plurality of coordinates representing the general shape of a part of a living body, such as the foot **132** shown in Figure **2**. The scanned body part may be any body part, or group of body parts in any particular orientation, for which it is desired to produce an appliance. For example, the body part in the embodiment shown in Figure **1** is a posterior region of a human patient's torso and legs and the scanned input coordinates are used to produce a supporting seat appliance for supporting the patient's body in a seated position.

In general the scanner **130** includes a structured light generator **134** for generating an illumination line, which illuminates the body part **132**. The scanner **130** also includes a sensor **136** which is calibrated to produce an image of the intersection of the illumination line with the body part **132**. The image is then processed by the scanner to extract a plurality of 3D input coordinates representing the body part **132**. 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.

In one embodiment the appliance **120** is custom produced for a particular patient and the patient's body part, such as the foot **132**, is scanned using the scanner **130**. The input plurality of coordinates thus represent an actual shape of the patient's foot and are received at the apparatus **102** and displayed as a representation at **138** on the display **110**. The operator may then use the pointing device **112** and the keyboard **114** to manipulate the representation **138** to provide a comfortably fitting appliance for the specific patient. Once the operator is satisfied with the appliance the modified appliance representation is output to the CAM machine **104** for machining of the final appliance.

Alternatively, a plurality of different body parts may be pre-scanned and stored in a library in the CAM apparatus **102**. The library may thus include representations of various body parts or various sizes and may be used to provide an input plurality of coordinates for the CAM apparatus **102**, which are then modified to suit a particular patient's requirements.

<u>Processor circuit</u>

The processor circuit **106** of the CAD apparatus **102** is shown in greater detail in Figure **3**. Referring to Figure **3**, the processor circuit **106** includes a microprocessor **140**, a program memory **144**, a random access memory (RAM) **148**, a hard-drive **150**, an input/output port **152**, and a media reader **154**, all of which are in communication with the microprocessor **140**.

Program codes for directing the microprocessor **140** to carry out various CAD functions are stored in the program memory **144**, which may be implemented as a random access memory (RAM), and/or a hard disc drive (HDD), or a combination thereof. The program memory **144** includes a block of codes **172** for directing the microprocessor **140** to provide general operating system (O/S) functions, and a **3**D representation block of codes **174** for directing the microprocessor **140** to provide functions for producing the computer representation of the three-dimensional surface of the appliance. The program memory **144** further includes a rotational transform function block of codes **176** for directing the microprocessor to apply a rotational transform to a portion of the three-dimensional 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 disc **158**, a flash memory (not shown), or a computer readable signal **160** such as would be received over a network such as the internet, for example. In one embodiment the media reader may also facilitate writing carving instructions to a CD ROM disk computer readable medium **156** for a manual transfer between the CAD apparatus **102** and the CAM machine **104**.

The RAM **148** includes a plurality of storage locations, including a store **180** for storing the input plurality of coordinates representing the appliance, a store **182** for storing rotational axis coordinates, a store **184** for storing constraints and blending parameters, a store **186** for storing a rotational transform magnitude, and a store **188** for storing an output plurality of coordinates.

The hard-drive **150** includes a plurality of storage locations for persistent storage of data, including a location **196** for storage of library shape data representing pre-scanned body parts.

The I/O **152** includes a first interface **162** having an input **164** for receiving signals encoded with the input plurality coordinates from the scanner **130** (shown in Figure **2**). The I/O **152** also includes a second interface **166** having an output **168** for producing the signal encoded with shape representation data or carving instructions for controlling the CAM machine **104** to produce the appliance. The interfaces **162** and **166** may be universal serial bus (USB) or RS**232** serial interfaces, for example. The I/O **152** further includes an output **170** for producing display signals for causing the representation **108** of the appliance to be displayed on the display **110**.

Operation

Referring to Figure **4**, a flowchart depicting blocks of code for directing the processor circuit **106** to apply the rotational transform to a portion of the three-dimensional representation of the appliance is shown generally at **200**. The blocks generally represent codes that may be read from the computer readable medium **156**, and stored in the program memory **144**, for directing the microprocessor **140** to perform various functions related to applying the rotational transform. The actual code to implement each block may be written in any suitable program language, such as C, C++, and/or assembly code for example.

Input coordinates

The process **200** begins at block **202** which directs the microprocessor **140** to receive an input plurality of coordinates representing a preliminary general shape of the appliance to be produced. In one embodiment, the input plurality of coordinates are read from the shape library **196** stored on the hard-drive **150**, and are written to the store **180** of the RAM **148** to facilitate modification of the library shape for producing a custom appliance for a patient.

The 3D representation **108**, such as would be displayed on the display **110** is shown in greater detail in Figure **5** at **220**. Referring to Figure **5**, the input plurality of coordinates represent locations of vertices **222** within a Cartesian coordinate system **224** having *x*, *y*, and *z* axes. The vertex locations **222** define a plurality of polygons **226** forming an interconnected surface polygon mesh defining a general shape of the appliance. Such a surface polygon mesh may be efficiently stored in store **180** or the RAM **148** as a list of vertex locations **222**, each having an associated list of connections to other vertices.

Referring to Figure **6**, a screenshot of an operator interface screen for displaying the preliminary 3D representation **220** and for facilitating modification of the 3D representation is shown generally at **250**. The operator interface **250** includes a window **252** for displaying a view of the preliminary 3D shape representation **220**. The operator interface **250** also includes a menu bar **254** for activating functions associated with receiving the input coordinates and displaying the representation **220**. The operator interface **250** also includes a toolbar **256**, including a plurality of actuator buttons providing for convenient invocation of some functions. For example, various CAD functions may be invoked to scale, move or rotate the 3D representation **220** within the window **252** to permit the operator to view various alternative views of the representation. In particular the toolbar **256** includes a "constrained rotation" button **258** for invoking the rotational transform function codes **176** (shown in Figure **3**).

In the embodiment shown, the representation **220** is displayed as a shaded appliance representation, where the polygons **226** have been shaded using a shading algorithm to display smooth surfaces in place of the polygon mesh shown in Figure **5**. In one embodiment a Gouraud shading algorithm is applied to the underlying polygons **226** to generate the displayed surface, as shown in Figure **6**.

<u>Rotational axis</u>

When the "constrained rotation" button **258** is selected by the operator using the pointing device **112**, the process **200** (shown in Figure **4**) continues at block **204**, which directs the microprocessor **140** to receive operator input identifying a coordinate location of a rotational axis about which the rotational transform is to be applied. In one embodiment, an operator interface window **260** is displayed, which facilitates receiving operator input identifying a desired coordinate location of a rotational axis. The rotational axis is represented in the window **252** by a 3D line **262** located at an initial or default location in the *xyz* coordinate system **224**. The operator interface window **260** includes direction input controls **264** allowing the operator to enter directional coordinates *x*, *y*, and *z* defining a direction of the rotational axis **262**. The operator interface window **260** further includes a control **266**, that when enabled, permits free rotation of the rotational axis **262** such that the operator can select an axis direction by clicking on the pitch, roll, and yaw controls **268** to change the direction of the axis. Alternatively, the operator may interactively modify the direction of the rotational axis **262** about a point **272** by clicking and dragging on handles **274** and **276** associated with the rotational axis. The location of the point **272** with respect to the representation **220** may also be changed by using the pointing device **112** to drag the rotational axis **262** to a new location while the axis direction remains unchanged.

In the embodiment shown in Figure **6**, the representation of the rotational axis also includes a reference plane **278** intersecting the rotational axis **262** at the point **272**. The reference plane **278** is oriented orthogonal to the rotational axis **262** and intersects the 3D representation **220** along an intersection line **280**. The rotational axis **262** defines a coordinate system **282** for applying the rotational transform to the 3D representation **220**. The coordinate system **282** has an origin at the point **272** on the reference plane **278**, a *w*-axis aligned with the rotational axis **262**, and *u* and *v*-axes lying in the reference plane **278**.

In one embodiment the location of the rotational axis **262** may be stored as a 3D modeling matrix *A* defining the location of the *uvw* coordinate system **282** with respect to the *xyz* coordinate system **224**:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 \\ a_{21} & a_{22} & a_{23} & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & 1 \end{bmatrix}, \qquad \text{Eqn } \mathbf{1}$$

where the elements a_{11}, a_{12}, and a_{13} represent a unit vector defining the *u*-axis of the coordinate frame, a_{21}, a_{22}, and a_{23} represent a unit vector defining the *v*-axis of the coordinate frame, and a_{31}, a_{32}, and a_{33} represent a unit vector defining the *w*-axis of the coordinate frame (i.e. the direction of the rotational axis **262**). The elements a_{41}, a_{42}, and a_{43} represent x, y, and z coordinates of the point **272** in the *xyz* coordinate system.

Referring back to Figure **4**, block **204** of the process **200** then directs the microprocessor **140** to store the coordinate location of the rotational axis **262** (i.e. the elements of the **3**D modeling matrix *A*) in the rotational axis coordinate store **182** of the RAM **148**.

Operator input of constraints

The process **200** then continues at block **206**, which directs the microprocessor **140** to receive operator input of at least one constraint defining an extent of a transform volume within which the rotational transform is to be applied to the representation of the appliance **220**.

Referring to Figure **7**, in one embodiment the at least one constraint comprises an axial constraint limiting an extent of the transform volume in a direction along the rotational axis **262**. The axial constraint is represented by an axial constraint plane **312** oriented orthogonal to the rotational axis **262**. In the embodiment shown the transform volume extends downwardly from the axial constraint plane **312** defining a portion **316** of the representation **220** to be modified by the rotational transform. The axial constraint plane **312** also defines a portion **314** of the **3**D representation **220** (located above the axial constraint plane **312**) that should remain un-modified after application of the rotational transform.

Referring to Figure **8**, in another embodiment the at least one constraint comprises first and second rotational constraints **320** and **322**, which are represented by respective rotational constraint planes extending outwardly from the rotational axis **262**. Together the first and second rotational constraints **320** and **322** define the transform volume within which the rotational transform is to be applied to the **3**D representation **220**. The first and second rotational constraints **320** and **322** limit an extent of the transform volume to a volume extending outwardly from the rotational axis and being bounded by the first and second rotational constraint planes. Portions of the **3**D representation **220** located within a circular sector **328** between the first and second rotational constraints **320** and **322** are to be modified by the rotational transform, while other portions within a circular sector **330** are to remain un-modified by the rotational transform.

Alternatively, in some embodiments the transform volume may be bounded by both rotational constraints, such as the first and second rotational constraints **320** and **322** shown in Figure **8**, and one or more axial constraints, such as the axial constraint plane **312** (shown in Figure **7**).

Referring to Figure **9**, a screenshot of the operator interface for receiving input of rotational and/or axial constraints is shown at **350**. The operator interface **350** includes a window **352** for displaying a two-dimensional (**2**D) view of the intersection line **280** with respect to the *u* and *v*-axes of the coordinate system **282**. In Figure **9**, the *w*-axis of the coordinate system **282** and the rotational axis **262** (shown in Figure **6**) are both located at the origin at point **272**.

The line of intersection **280** is generated by determining which of the polygons **226** (shown in Figure **5**) intersect the reference plane **278** by computing a distance between each vertex **222** of each polygon, and determining whether the vertices all lie on the same side of the reference plane. Methods for computing a signed distance between an arbitrary point and a plane are well known in the art. A polygon that has at least one vertex **222** located on an opposite side of the reference plane to the remaining polygon vertices, intersects with the reference plane **278**. The intersection of this polygon with the reference plane defines a line segment, such as the exemplary line segment **380** shown in Figure **9**. The line segment **380** has a pair of endpoints **382** and **384**, each of which lie on one of the edges of the intersecting polygon defined by adjacent vertices. The computed distances between the vertices and the reference plane may then be used to interpolate between the coordinates of the adjacent vertices to obtain the coordinate locations of the endpoints. The line of intersection **280** is thus made up of a plurality of line segments, such as the line segment **380**.

The operator interface **350** includes a checkbox field **354**, which when activated by clicking on the checkbox causes the first and second rotational constraints **320** and **322** to be activated and displayed. The first and second rotational constraints **320** and **322** appear in the window **352** as respective rotational constraint lines extending outwardly from the rotational axis **262**. The rotational constraints **320** and **322** each have respective controls **360** and **362** that facilitate interactive positioning of the rotational constraints with respect to the intersection line **280** when the controls are clicked and dragged using the pointing device **112**. The first rotational constraint **320** is oriented at an angle α_1 to the *u*-axis and the second rotational constraint **322** is oriented at an angle α_2 to the *u*-axis. In the embodiment shown in Figure **9**, the intersection line **280** represents a cross section through the seat appliance **220** and the second rotational constraint **322** is oriented such that a right leg portion and a posterior region of the seat appliance **220** will remain un-modified by the rotational transform.

In embodiments such as that shown in Figure **9** and Figure **10**, where rotational constraints are activated, only a portion of the 3D representation lying within the transform volume is subjected to the rotational transform. To avoid producing shape discontinuity at the edges of the transform volume, rotational blending may be applied in the region of the rotational constraints to cause continuity of shape between modified portions of the representation and un-modified portions of the representation following application of the rotational transform.

In the embodiment shown, the operator interface **350** includes a slider control **378** which facilitates receiving operator input of a blending parameter *k* that controls application of the rotational blending, as described later herein. The operator interface **350** further includes a slider control **377** which facilitates receiving operator input of a desired size of the no-blending zone **376**. The no-blending zone **376** extends between a line **372** at an angle α_3 to the *u*-axis and a line **374** at an angle α_4 to the *u*-axis and is centered on the reference line **358**. The lines **372** and **374** also define respective rotational blending regions extending between the rotational constraint **320** and the line **372**, and the line **374** and the second rotational constraint **322**. In general, a full magnitude of the rotational transform is applied in the no-blending zone **376**, while in the rotational blending zones the applied magnitude of the rotational transform is reduced in proximity to the rotational constraints **320** and **322**. The effect of the rotational blending regions and the no-blending zone **376** is described in greater detail later herein.

The operator interface **350** also includes a checkbox field **386**, which when activated by clicking on the checkbox causes a first axial constraint to be activated (such as the axial constraint **312** shown in Figure **7**). The operator interface **350** also includes a checkbox field **387**, which when activated by clicking on the checkbox causes a second axial constraint to be activated. In the embodiment shown, only the first axial constraint is activated. When an axial constraint is activated, a constraint plane such as the plane **312** shown in Figure **7** is displayed, and may be dragged to a location along the rotational axis **262** in response to operator input. In the example shown, the axial constraint plane **312** is located a distance c_1 along the rotational axis **262** from the reference plane **278**. The axial constraint plane **312** is thus located at $w = c_1$. Similarly, if a second constraint is activated by the operator clicking the checkbox field **387**, a second constraint plane would be located at a location $w = c_2$.

The operator interface **350** further includes a slider control **388**, which facilitates receiving operator input of size h_c of an axial blending region, which is stored in the constraints store **184** of the RAM **148**. When an axial constraint is activated, the axial blending region extends from the axial constraints into the transform volume. In general the axial blending is operable to cause continuity of shape between modified portions of the representation of the appliance within the transform volume and un-modified portions of the representation of the appliance outside the transform volume.

The application of axial blending within the axial blending regions is described later herein.

Referring back to Figure **4**, block **206** of the process **200** then directs the microprocessor **140** to store the values of the constraints α_1 and α_2, the no-blending zone angles α_3 and α_4, and the blending parameter k in the constraints store **184** of the RAM **148** (shown in Figure **3**). Block **206** also directs the microprocessor **140** to store the values of the constraint plane locations c_1 and c_2 in the constraints store **184** of the RAM **148**.

<u>Operator input of rotational transform magnitude</u>

The process **200** then continues at block **208** which directs the microprocessor **140** to receive operator input of a magnitude of the rotational transform to be applied to the portion of the representation of the appliance within the transform volume. Referring again to Figure **9**, in this embodiment the magnitude of the rotational transform to be applied is defined with respect to a reference line **358** displayed in the window **352**. The reference line **358** extends outwardly from the rotational axis **262** and is located at a reference angle θ from the u-axis. The reference line **358** includes a first control **364** for setting a reference angle θ for the rotational transform, which allows the operator to align the reference line with a particular feature of the appliance (in this case the reference line **358** is generally centered on the left limb portion).

The operator interface **350** also includes a second control **366** for setting the rotational transform magnitude M_0 with respect to the reference line **358**. The operator interface **350** further includes a magnitude field **368**, which is linked to the second control **366** for displaying and/or receiving operator input of the rotational transform magnitude M_0. Initially as shown in Figure **9**, the second control **366** lies on the reference line **358** and the magnitude field **368** displays a value of $M_0 =$ ***0.0°*** (i.e. zero magnitude). As shown in Figure **10**, when a non-zero angular magnitude value is entered into the magnitude field **368** (M_0

= ***-13.7°*** in this case), the second control **366** moves to a new location along with the line **370**. The line **370** is angularly displaced from the reference line **358** by the entered value of the angular magnitude M_0. In this embodiment a sign convention is implemented such that anti-clockwise displacements are given a negative sign, while clockwise displacements are given a positive sign. Alternatively, the operator may also drag the second control **366** to a desired new location, causing the line **370** to be displayed as shown while the magnitude field **368** is updated to reflect the angular location of the line **370** with respect to the reference line **358**. The control **364** and the reference line **358** remain located at the zero magnitude reference angle θ.

Referring back to Figure **4**, block **208** of the process **200** then directs the microprocessor **140** to store the values of the reference angle α_3 and the magnitude M_0 (in this case M_0 = **-13.7°**) in the rotational transform magnitude store **186** of the RAM **148** shown in Figure **3**.

Following execution of the codes represented by block **208** in Figure **4**, all necessary parameters are available for computing a rotational magnitude that should be applied to each of the input plurality of coordinates within the transform volume. Referring to Figure **11**, a graphical depiction of an angular mapping between initial angle and final angle is shown generally at **400**. The graph **400** maps an initial angle θ for any point on the intersection line 280 (for example the point **390** shown in Figure **9**) to a final angle θ' for the point (shown in Figure **10**). Points lying in a region **402** and in a region **404** are mapped **1**:**1** and thus remain un-modified i.e. for $0° \leq \theta \leq \alpha_1$ and for $\alpha_2 \leq \theta < 360°$:

$$M(\theta) = 0 . \quad \text{Eqn 2}$$

Points lying in an expansion region **408** are rotated by progressively increasing angular displacements up to the full magnitude M_0 to provide continuity with the region **402** at the second rotational constraint. For the region **408**, i.e. for $\alpha_1 \leq \theta < \alpha_3$, define $w = \frac{\theta - \alpha_1}{\alpha_3 - \alpha_1}$, then

for $0 < w \leq 0.5$:

$$M(\theta) = \frac{M_0}{2}(2w)^k,$$

for $0.5 < w \leq 1$:

$$M(\theta) = \frac{M_0}{2}(2 - (2 - 2w)^k). \qquad \text{Eqn } \mathbf{3}$$

The above blending functions yield $M(\theta)=0$ when $w = 0$, $M(\theta)=M_0/2$ when $w = 0.5$, and $M(\theta)=M_0$ when $w = 1$. The maximum slope of the blending function occurs at $w = 0.5$ and the parameter k, which usually ranges between **1** and **4**, determines the steepness of the slope and thus the shape of the blending in the expansion region **408**.

Points lying in the no-blending region **406** are rotated by the full rotational transform magnitude M_0, i.e. for $\alpha_3 \leq \theta < \alpha_4$:

$$M(\theta) = M_0 \qquad \text{Eqn } \mathbf{4}$$

Points lying in a compression region **410** are rotated by progressively reducing angular displacements to provide continuity with the region **404** at the first rotational constraint i.e. for $\alpha_4 \leq \theta < \alpha_2$, define $w = \frac{\theta - \alpha_4}{\alpha_2 - \alpha_4}$, then

for $0 < w \leq 0.5$:

$$M(\theta) = \frac{M_0}{2}(2 - (2 - 2w)^k), \text{ and}$$

for $0.5 < w \leq 1$:

$$M(\theta) = \frac{M_0}{2}(2w)^k \qquad \text{Eqn } \mathbf{5}$$

The equations **2** – **5** provided above may be used to calculate the rotational transform magnitude that should be applied performing the rotational transform. Alternatively, the graph **400** shown in Figure **11** may be saved as a look-up table mapping initial angle θ to final angle θ'.

Applying the rotational transform

Still referring to Figure **4**, block **210** then directs the microprocessor **140** to invoke the rotational transform function **176** in the program memory **144**.

Referring to Figure **12**, a flowchart depicting blocks of code for directing the microprocessor **140** to apply the rotational transform to the portion of the **3**D appliance representation within the transform volume is shown generally at **420**. The process begins at block **422**, which directs the microprocessor **140** to read the coordinates of a first vertex in the input plurality of coordinates from the store **180** of the RAM **148**. Each vertex may be represented by a vector:

$$\overline{P} = \begin{bmatrix} P_x & P_y & P_z & 1 \end{bmatrix}.$$

Block **424** then directs the microprocessor **140** to determine coordinates of the vector $\overline{P}$ in the *uvw* coordinate system by reading the **3**D modeling matrix *A* from the store **182** of the RAM **148** and computing the inverse of *A*. The *uvw* coordinates of the vector $\overline{P}$ are obtained as follows:

$$\overline{P}_{uvw} = \overline{P}A^{-1}. \qquad \text{Eqn } \mathbf{6}$$

Block **426** then directs the microprocessor **140** to determine whether the vertex lies within the axial constraint planes. If only one axial constraint plane is active, as shown in Figure **7**, any *w*-coordinate value that is less than c_1 identifies the vertex as lying within the axial constraints. When more than one constraint is active, the w-coordinate must have a value between c_2 and c_1 for the vertex to lie within the axial constraints. If at block **426** the *w*-coordinate lies outside the constraint planes, then the process continues at **428**, which directs the microprocessor **140** to read the *xyz* coordinates of next vertex. Block **428** then directs the microprocessor **140** back to block **424**.

If at block **426** the *w*-coordinate lies within the constraint planes, then the process continues at **430**. Block **430** directs the microprocessor **140** to compute the angle θ within the *uv* plane for the vertex as follows:

$$\theta = \arctan\left(\frac{u}{v}\right). \qquad \text{Eqn } \mathbf{7}$$

The process then continues at block **432** which directs the microprocessor **140** to use Eqn's **2** – **5** to compute rotational transform magnitude $M(\theta)$ for the vertex, using the value of θ computed at block **430**.

Block **434** then directs the microprocessor **140** to determine whether the vertex lies within the axial blending region defined by the axial blending parameter h_c. If the vertex lies outside the axial blending regions, then the process continues at block **436**, which directs the microprocessor **140** to set the angular displacement Φ of the vertex to the value of $M(\theta)$ determined at block **432**.

If at block **434** the vertex lies inside the axial blending regions, then the process continues at block **440**, which directs the microprocessor **140** to determine the angular displacement Φ of the vertex by multiplying the value of $M(\theta)$ determined at block **432** by a blending function $\Delta(h_c)$. In one embodiment blending is applied in accordance with a cubic polynomial:

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

where h is a distance into the transform volume from the first or second constraint and h_c is the size or extent of the axial blending region.

The process then continues at block **438** which directs the microprocessor **140** to compute a rotational transform matrix $T(\Phi)$ for applying the rotational displacement *Φ* computed at block **436** or **440** to the vector $\overline{P}$, in order determine coordinates of the rotated vertex in the *xyz* coordinate system. For rotation of the vector $\overline{P}$ through an angle *Φ* about the rotational axis **262** passing through a point Q taken as the point of intersection **272** between the reference plane **278** and the rotational axis **262**, where:

$$Q = \begin{bmatrix} Q_x & Q_y & Q_z \end{bmatrix},$$

and where the axis has a direction $\overline{U}$:

$$\overline{U} = \begin{bmatrix} U_x & U_y & U_z \end{bmatrix},$$

the rotational transform matrix *T(Φ)* is given by:

$$T(\phi) = \begin{bmatrix} \begin{bmatrix} & & \\ & T_{u,\phi} & \\ & & \end{bmatrix} & \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \\ \begin{bmatrix} & Q - QT_{u,\phi} & \end{bmatrix} & \begin{bmatrix} 1 \end{bmatrix} \end{bmatrix}, \qquad \text{Eqn } \mathbf{9}$$

where $T_{u,\Phi}$ is a **3x3** sub-matrix:

$$T_{u,\phi} = (\cos\phi)I + (1-\cos\phi)\overline{U} \otimes \overline{U} + (\sin\phi)\widetilde{U}, \qquad \text{Eqn } \mathbf{10}$$

and where:

$I = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$, a **3x3** unit matrix;

$\widetilde{U} = \begin{bmatrix} 0 & -U_z & U_y \\ U_z & 0 & -U_x \\ -U_y & U_x & 0 \end{bmatrix}$, i.e. a skew symmetric matrix; and

$\overline{U} \otimes \overline{U} = \begin{bmatrix} U_xU_x & U_xU_y & U_xU_z \\ U_yU_x & U_yU_y & U_yU_z \\ U_zU_x & U_xU_y & U_zU_z \end{bmatrix}$, the tensor product of U with itself.

The transformation matrix $T(\Phi)$ is computed for each vertex $\overline{P}$, and the modified **3**D *xyz* coordinates of the vertex are determined by the following matrix multiplication:

$$\overline{P}' = \overline{P}\,T(\phi). \qquad \text{Eqn } \mathbf{11}$$

Block **442** then directs the microprocessor **140** to store the modified *xyz* coordinates for the vertex in the P' in the store **188** of the RAM **148**.

Block **444** then directs the microprocessor **140** to determine whether the last vertex has been processed. If further vertices remain to be processed then block **444** directs the microprocessor **140** to block **428**, which directs the microprocessor to read *xyz* coordinates of the next vertex from the store **180** of the RAM **148**. Block **428** then directs the microprocessor **140** back to block **424**.

If at block **444**, the last vertex has been processed then all vertices within the transform volume have been processed and the process **420** ends at **446**. The output plurality of coordinates representing the final appliance may be displayed on the display 110, as shown in Figure 6.

<u>Example **1**</u>

In one example, the process described above may be applied to modify a library shape of an ankle/foot orthotic appliance to turn the foot portion relative to the leg portion to accommodate for a patient's adduction (draw toward the midline of the body) or abduction (draw away from the midline of the body). Referring to Figure **13**, in an abduction example, it is desired to modify a library shape **550** to cause a foot portion **552** to be shifted outwardly in the direction shown by the arrow **554**. In this embodiment, a rotational axis **556** is defined as described above in connection with Figure **6**, where the axis is oriented passing generally through an ankle portion (not shown) of the foot. A reference plane **558** is located passing through the foot and an axial constraint plane **560** is defined partway up the leg of the appliance **550**. The axial constraint plane **560** defines a portion **562** of the appliance **550** that is to be modified by the rotational transform and a portion **564** of the appliance that is to remain un-modified.

The operator interface **350** for this embodiment is shown in Figure **14**. Referring to Figure **14**, the window **352** of the operator interface **350** displays a **2**D view of the intersection of the appliance with the reference plane, and in this case the operator has entered a rotational magnitude of **7**.**5**° in the magnitude field **368**. In this embodiment, the transform volume encompasses the entire foot portion below the axial constraint plane **560** and no rotational constraints are selected. Accordingly, there is no rotational blending to be accounted for when applying the rotational transform and a the full magnitude $M(\theta) = M_0 = 7.5°$ is applied to all vertices below the axial constraint plane **560**. Since an axial constraint is active, blending is applied proximate to the axial constraint plane **560** as described above in accordance with the selected value of h_c. The window **352** displays an initial location **570** and a final location **572** of the portion of the foot lying in the reference plane.

<u>Example 2</u>

In another example, the process described above may be applied to modify a library shape of a knee brace by changing a hinge direction. Referring to Figure **15**, a library shape **580** of a knee brace is shown having hinge flats **582** and **584**, and for which it is desired to rotate the hinge direction in the direction indicated by the arrow **585**. A rotational axis **586** is defined as described above in connection with Figure **6**, where the axis is oriented passing generally through the center of an upper limb portion **588**, knee portion **590**, and lower limb portion **592**. A reference plane **594** is located passing through the knee portion **590**. A first axial constraint plane **596** is located above the knee portion **590** to prevent the upper limb portion **588** from being modified by the rotational transform. Similarly, a second axial constraint plane **598** is located below the knee portion **590** to prevent the lower limb portion **592** from being modified by the rotational transform.

The operator interface **350** for this embodiment is shown in Figure **16**. Referring to Figure **16**, the window **352** of the operator interface **350** displays a **2**D view of the intersection of the appliance with the reference plane, and in this case the operator has entered a rotational magnitude of -**10**° in the magnitude field **368**. In this example, the entire knee portion is to be rotated and accordingly, no rotational constraints are selected and the full magnitude $M(\theta) = M_0 = -10°$ is applied to all vertices between the first and second axial constraint planes **596** and **598**. Blending is applied proximate to each of the axial constraint planes **596** and **598** to preserve continuity between the knee portion **590** and the upper and lower limb portions **588** and **592** respectively. The window **352** displays an initial location **600** and a final location **602** of the portion of the foot lying in the reference plane.

Advantageously, the process described herein facilitates rotation of a **3**D shape, such that only a portion of the shape is altered by the **3**D rotation. The process also permits the rotation to occur about an operator specified axis. Blending between modified and un-modified portions of the shape prevent discontinuities being introduced by the modifications.

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 rotational transform to a portion of a three-dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates stored in a processor circuit memory, the input plurality of coordinates representing a general shape of the appliance, the method comprising:

receiving operator input identifying a coordinate location of a rotational axis about which the rotational transform is to be applied;

receiving operator input of at least one constraint defining an extent of a transform volume within which the rotational transform is to be applied to the representation of the appliance;

receiving operator input of a rotational transform magnitude;

applying the rotational transform to the portion of the representation of the appliance within the transform volume to produce an output plurality of coordinates representing a modified shape of the appliance such that the general shape of portions of the appliance outside the transform volume remain un-modified by the rotational transform; and

storing the output plurality of coordinates in the processor circuit memory.

2. The method of claim **1** further comprising generating a set of instructions operable to control a computer aided manufacturing machine to produce one of the appliance and a mold for producing the appliance in accordance with said output plurality of coordinates.

3. The method of claim **1** further comprising generating display signals operable to cause a representation of the output plurality of coordinates to be displayed on a display associate with the processor circuit.

4. The method of claim **1** wherein receiving said operator input of said at least one constraint comprises receiving operator input of at least one axial constraint limiting an extent of the transform volume in a direction along the rotational axis.

5. The method of claim **4** wherein receiving said operator input defining said at least one axial constraint comprises receiving operator input defining at least one constraint plane oriented orthogonal to the rotational axis and intersecting the appliance representation.

6. The method of claim **4** wherein receiving said operator input defining said at least one axial constraint comprises receiving operator input defining first and second spaced apart axial constraints along the rotational axis, the first and second axial constraints limiting an extent of the transform volume to between the first and second axial constraints.

7. The method of claim **4** further comprising:

identifying an axial blending region extending into said transform volume from said at least one axial constraint; and

wherein applying the rotational transform comprises reducing a magnitude of the rotational transform within said axial blending region to cause continuity of shape between modified portions of the representation of the appliance within said transform volume and un-modified portions of the representation of the appliance outside said transform volume.

8. The method of claim **7** wherein reducing said magnitude of the rotational transform comprises applying a rotational transform having:

substantially zero magnitude at said axial constraint; and

a magnitude that progressively increases with distance away from said at least one axial constraint to reach a full rotational transform magnitude beyond said axial blending region.

9. The method of claim **8** wherein identifying said axial blending region comprises receiving operator input of a distance defining an extent of said blending region into the transform volume.

10. The method of claim **1** wherein receiving said operator input of said at least one constraint comprises receiving operator input of first and second rotational constraints with respect to the rotational axis, said first and second rotational constraints defining an angular extent of said transform volume about said rotational axis.

11. The method of claim **10** wherein applying the rotational transform to said portion of the three-dimensional representation of the appliance within said transform volume comprises:

identifying first and second rotational blending regions extending from said first and second rotational constraints into said transform volume; and

wherein applying the rotational transform comprises reducing a magnitude of the rotational transform within said first and second rotational blending regions respectively to cause continuity of shape between modified portions of the representation of the appliance within said transform volume and un-modified portions of the representation of the appliance outside said transform volume.

12. The method of claim **11** wherein reducing said magnitude of the rotational transform comprises applying a rotational transform having:

substantially zero magnitude at said first and second rotational constraints; and

a magnitude that progressively increases with rotational displacement into said transform volume to reach a full rotational transform magnitude beyond said first and second rotational blending regions respectively.

13. The method of claim **11** wherein identifying said first and second rotational blending regions comprises receiving operator input defining a rotational extent of said first and second rotational blending regions into the transform volume.

14. The method of claim **11** wherein identifying said first and second rotational blending regions comprises:

receiving operator input of a no-blending zone located between said first and second rotational constraints, said no-blending zone defining an angular extent of the transform volume about said rotational axis within which a full magnitude of the rotational transform is to be applied, and wherein said first and second rotational blending regions respectively comprise portions of the transform volume outside said no-blending zone.

15. The method of claim **1** further comprising receiving operator input of a desired rotational magnitude and direction of the rotational transform to be applied to said portion of the three-dimensional representation of the appliance within said transform volume.

16. The method of claim **15** further comprising:

defining a reference plane oriented orthogonal to the rotational axis and intersecting the appliance representation;

displaying a two-dimensional view of an intersection between the three dimensional representation of the appliance and said reference plane;

wherein receiving said operator input of said desired magnitude and direction of the rotational transform to be applied comprises:

receiving an operator selection of a reference point on said reference plane; and

receiving operator input of a desired rotational displacement of said reference point.

17. The method of claim **16** further comprising displaying a modified shape of said intersection in said two-dimensional view.

18. The method of claim **1** wherein applying the rotational transform comprises for each input coordinate in the input plurality of coordinates:

determining an angular displacement to be applied to the input coordinate; and

generating a rotational transformation matrix for the input coordinate, said rotational transform matrix including elements operable to transform said input coordinate into an output coordinate that is angularly displaced from said input coordinate by said angular displacement about the rotational axis.

19. The method of claim **18** wherein the input plurality of coordinates are defined in a first Cartesian coordinate system and further comprising generating a modeling matrix having elements operable to transform input coordinates between said first coordinate system and a second Cartesian coordinate system, said second coordinate system having an origin located on said rotational axis, a first axis aligned with said rotational axis, and second and third axes orthogonal to said rotational axis, and wherein determining said angular displacement comprises:

determining a corresponding coordinate of said input coordinate in said second coordinate system; and

determining an angular displacement of each said corresponding coordinate within a plane defined by said second and third axes of said second coordinate system.

20. The method of claim **1** wherein receiving operator input identifying said coordinate location of said rotational axis comprises receiving operator input defining:

coordinates of a three-dimensional line representing a location of the rotational axis with respect to the appliance representation;

a location of a reference plane intersecting the appliance representation and oriented orthogonal to the three-dimensional line; and a location of an origin point on the reference plane through which the rotational axis passes.

21. The method of claim **20** further comprising displaying a three-dimensional representation of said appliance, said reference plane, and said three-dimensional line and wherein receiving said operator input comprises receiving pointer signals from a pointing device in communication with the processor circuit, the pointing signals being operable to define desired changes to said coordinates of at least one of said three-dimensional line, said location of said reference plane, and said location of said origin point on said reference plane with respect to said appliance.

22. The method of claim **21** further comprising displaying a two-dimensional view of the intersection of the general shape of the appliance with the reference plane and wherein receiving said operator input comprises receiving pointer signals from said pointing device, the pointing signals being operable to define desired changes to said origin point on said reference plane.

23. The method of claim **1** wherein applying the rotational transform to the portion of the three-dimensional representation of the appliance within the transform volume to produce an output plurality of coordinates comprises:

producing modified coordinates representing said modified shape of the appliance within said transform volume; and

resampling said modified coordinates and said un-modified coordinates outside said transform volume to produce said output plurality of coordinates representing said modified appliance representation.

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

receive operator input identifying a coordinate location of a rotational axis about which the rotational transform is to be applied;

receive operator input of at least one constraint defining an extent of a transform volume within which the rotational transform is to be applied to the representation of the appliance;

receive operator input of a rotational transform magnitude;

apply the rotational transform to the portion of the representation of the appliance within the transform volume to produce an output plurality of coordinates representing a modified shape of the appliance such that the general shape of portions of the appliance outside the transform volume remain un-modified by the rotational transform; and

store the output plurality of coordinates in a memory of the processor circuit.

25. The apparatus of claim **24** wherein said processor circuit is operably configured to generate a set of instructions operable to control a computer aided manufacturing machine to produce one of the appliance and a mold for producing the appliance in accordance with said output plurality of coordinates.

26. The apparatus of claim **24** wherein said processor circuit is operably configured to generate display signals operable to cause a representation of the output plurality of coordinates to be displayed.

27. The apparatus of claim **24** wherein said processor circuit is operably configured to receive said operator input of said at least one constraint by receiving operator input of at least one axial constraint limiting an extent of the transform volume in a direction along the rotational axis.

28. The apparatus of claim **27** wherein said processor circuit is operably configured to receive said operator input defining said at least one axial constraint by receiving operator input defining at least one constraint plane oriented orthogonal to the rotational axis and intersecting the appliance representation.

29. The apparatus of claim **27** wherein said processor circuit is operably configured to receive said operator input defining said at least one axial constraint by receiving operator input defining first and second spaced apart axial constraints along the rotational axis, the first and second axial constraints limiting an extent of the transform volume to between the first and second axial constraints.

30. The apparatus of claim **27** wherein said processor circuit is operably configured to:

identify an axial blending region extending into said transform volume from said at least one axial constraint; and

wherein said processor circuit is operably configured to apply the rotational transform by reducing a magnitude of the rotational transform within said axial blending region to cause continuity of shape between modified portions of the representation of the appliance within said transform volume and un-modified portions of the representation of the appliance outside said transform volume.

31. The apparatus of claim **30** wherein said processor circuit is operably configured to reduce said magnitude of the rotational transform by applying a rotational transform having:

substantially zero magnitude at said axial constraint; and

a magnitude that progressively increases with distance away from said at least one axial constraint to reach a full rotational transform magnitude beyond said axial blending region.

32. The apparatus of claim **31** wherein said processor circuit is operably configured to identify said axial blending region by receiving operator input of a distance defining an extent of said blending region into the transform volume.

33. The apparatus of claim **24** wherein said processor circuit is operably configured to receive said operator input of said at least one constraint by receiving operator input of first and second rotational constraints with respect to the rotational axis, said first and second rotational constraints defining an angular extent of said transform volume about said rotational axis.

34. The apparatus of claim **33** wherein said processor circuit is operably configured to apply the rotational transform to said portion of the three-dimensional representation of the appliance within said transform volume by:

identifying first and second rotational blending regions extending from said first and second rotational constraints into said transform volume; and

wherein said processor circuit is operably configured to apply the rotational transform by reducing a magnitude of the rotational transform within said first and second rotational blending regions respectively to cause continuity of shape between modified portions of the representation of the appliance within said transform volume and un-modified portions of the representation of the appliance outside said transform volume.

35. The apparatus of claim **34** wherein said processor circuit is operably configured to reduce said magnitude of the rotational transform by applying a rotational transform having:

substantially zero magnitude at said first and second rotational constraints; and

a magnitude that progressively increases with rotational displacement into said transform volume to reach a full rotational transform magnitude beyond said first and second rotational blending regions respectively.

36. The apparatus of claim **34** wherein said processor circuit is operably configured to identify said first and second rotational blending regions by receiving operator input defining a rotational extent of said first and second rotational blending regions into the transform volume.

37. The apparatus of claim **34** wherein said processor circuit is operably configured to identify said first and second rotational blending regions by:

receiving operator input of a no-blending zone located between said first and second rotational constraints, said no-blending zone defining an angular extent of the transform volume about said rotational axis within which a full magnitude of the rotational transform is to be applied, and wherein said first and second rotational blending regions respectively comprise portions of the transform volume outside said no-blending zone.

38. The apparatus of claim **24** wherein said processor circuit is operably configured to receive operator input of a desired rotational magnitude and direction of the rotational transform to be applied to said portion of the three-dimensional representation of the appliance within said transform volume.

39. The apparatus of claim **38** wherein said processor circuit is operably configured to:

define a reference plane oriented orthogonal to the rotational axis and intersecting the appliance representation;

display a two-dimensional view of an intersection between the three dimensional representation of the appliance and said reference plane;

wherein said processor circuit is operably configured to receive said operator input of said desired magnitude and direction of the rotational transform to be applied by:

receiving an operator selection of a reference point on said reference plane; and receiving operator input of a desired rotational displacement of said reference point.

40. The apparatus of claim **39** wherein said processor circuit is operably configured to display a modified shape of said intersection in said two-dimensional view.

41. The apparatus of claim **24** wherein said processor circuit is operably configured to apply the rotational transform by:

determining an angular displacement to be applied to each input coordinate in the input plurality of coordinates; and

generating a rotational transformation matrix for the input coordinate, said rotational transform matrix including elements operable to transform said input coordinate into an output coordinate that is angularly displaced from said input coordinate by said angular displacement about the rotational axis.

42. The apparatus of claim **41** wherein the input plurality of coordinates are defined in a first Cartesian coordinate system and wherein said processor circuit is operably configured to generate a modeling matrix having elements operable to transform input coordinates between said first coordinate system and a second Cartesian coordinate system, said second coordinate system having an origin located on said rotational axis, a first axis aligned with said rotational axis, and second and third axes orthogonal to said rotational axis, and wherein said processor circuit is operably configured to determine said angular displacement by:

determining a corresponding coordinate of said input coordinate in said second coordinate system; and determining an angular displacement of each said corresponding coordinate within a plane defined by said second and third axes of said second coordinate system.

43. The apparatus of claim **24** wherein said processor circuit is operably configured to receive operator input identifying said coordinate location of said rotational axis by receiving operator input defining:

coordinates of a three-dimensional line representing a location of the rotational axis with respect to the appliance representation;

a location of a reference plane intersecting the appliance representation and oriented orthogonal to the three-dimensional line; and

a location of an origin point on the reference plane through which the rotational axis passes.

44. The apparatus of claim **43** wherein said processor circuit is operably configured to display a three-dimensional representation of said appliance, said reference plane, and said three-dimensional line and wherein said processor circuit is operably configured to receive said operator input by receiving pointer signals from a pointing device in communication with the processor circuit, the pointing signals being operable to define desired changes to said coordinates of at least one of said three-dimensional line, said location of said reference plane, and said location of said origin point on said reference plane with respect to said appliance.

45. The apparatus of claim **44** wherein said processor circuit is operably configured to display a two-dimensional view of the intersection of the general shape of the appliance with the reference plane and wherein said processor circuit is operably configured to receive said operator input by receiving pointer signals from said pointing device, the pointing signals being operable to define desired changes to said origin point on said reference plane.

46. The apparatus of claim **24** wherein said processor circuit is operably configured to apply the rotational transform to the portion of the three-dimensional representation of the appliance within the transform volume to produce an output plurality of coordinates by:

producing modified coordinates representing said modified shape of the appliance within said transform volume; and

resampling said modified coordinates and said un-modified coordinates outside said transform volume to produce said output plurality of coordinates representing said modified appliance representation.

47. A computer readable medium encoded with codes for directing a processor circuit to apply a rotational transform to a portion of a three-dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates stored in a processor circuit memory, the input plurality of coordinates representing a general shape of the appliance, the codes directing the processor circuit to:

receive operator input identifying a coordinate location of a rotational axis about which the rotational transform is to be applied;

receive operator input of at least one constraint defining an extent of a transform volume within which the rotational transform is to be applied to the representation of the appliance;

receive operator input of a rotational transform magnitude;

apply the rotational transform to the portion of the representation of the appliance within the transform volume to produce an output plurality of coordinates representing a modified shape of the appliance such that the general shape of portions of the appliance outside the transform volume remain un-modified by the rotational transform; and

store the output plurality of coordinates in a memory of the processor circuit.

48. A computer readable signal encoded with codes for directing a processor circuit to apply a rotational transform to a portion of a three-dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates stored in a processor circuit memory, the input plurality of coordinates representing a general shape of the appliance, the codes directing the processor circuit to:

receive operator input identifying a coordinate location of a rotational axis about which the rotational transform is to be applied;

receive operator input of at least one constraint defining an extent of a transform volume within which the rotational transform is to be applied to the representation of the appliance;

receive operator input of a rotational transform magnitude;

apply the rotational transform to the portion of the representation of the appliance within the transform volume to produce an output plurality of coordinates representing a modified shape of the appliance such that the general shape of portions of the appliance outside the transform volume remain un-modified by the rotational transform; and

store the output plurality of coordinates in a memory of the processor circuit.

49. An apparatus for applying a rotational transform to a portion of a three-dimensional representation of an appliance for a living body, the representation being defined by an input plurality of coordinates stored in a processor circuit memory, the input plurality of coordinates representing a general shape of the appliance, the apparatus comprising:

means for receiving operator input identifying a coordinate location of a rotational axis about which the rotational transform is to be applied;

means for receiving operator input of at least one constraint defining an extent of a transform volume within which the rotational transform is to be applied to the representation of the appliance;

means for receiving operator input of a rotational transform magnitude;

means for applying the rotational transform to the portion of the representation of the appliance within the transform volume to produce an output plurality of coordinates representing a modified shape of the appliance such that the general shape of portions of the appliance outside the transform volume remain un-modified by the rotational transform; and

means for storing the output plurality of coordinates in the processor circuit memory.

50. The apparatus of claim **49** further comprising means for generating a set of instructions operable to control a computer aided manufacturing machine to produce one of the appliance and a mold for producing the appliance in accordance with said output plurality of coordinates.

51. The apparatus of claim **49** further comprising means for generating display signals operable to cause a representation of the output plurality of coordinates to be displayed on a display associate with the processor circuit.

52. The apparatus of claim **49** wherein said means for receiving said operator input of said at least one constraint comprises means for receiving operator input of at least one axial constraint limiting an extent of the transform volume in a direction along the rotational axis.

53. The apparatus of claim **52** wherein said means for receiving said operator input defining said at least one axial constraint comprises means for receiving operator input defining at least one constraint plane oriented orthogonal to the rotational axis and intersecting the appliance representation.

54. The apparatus of claim **52** wherein said means for receiving said operator input defining said at least one axial constraint comprises means for receiving operator input defining first and second spaced apart axial constraints along the rotational axis, the first and second axial constraints limiting an extent of the transform volume to between the first and second axial constraints.

55. The apparatus of claim **52** further comprising:

means for identifying an axial blending region extending into said transform volume from said at least one axial constraint; and

wherein said means for applying the rotational transform comprises means for reducing a magnitude of the rotational transform within said axial blending region to cause continuity of shape between modified portions of the representation of the appliance within said transform volume and un-modified portions of the representation of the appliance outside said transform volume.

56. The apparatus of claim **55** wherein said means for reducing said magnitude of the rotational transform comprises means for applying a rotational transform having:

substantially zero magnitude at said axial constraint; and

a magnitude that progressively increases with distance away from said at least one axial constraint to reach a full rotational transform magnitude beyond said axial blending region.

57. The apparatus of claim **56** wherein said means for identifying said axial blending region comprises means for receiving operator input of a distance defining an extent of said blending region into the transform volume.

58. The apparatus of claim **49** wherein said means for receiving said operator input of said at least one constraint comprises means for receiving operator input of first and second rotational constraints with respect to the rotational axis, said first and second rotational constraints defining an angular extent of said transform volume about said rotational axis.

59. The apparatus of claim **58** wherein said means for applying the rotational transform to said portion of the three-dimensional representation of the appliance within said transform volume comprises:

means for identifying first and second rotational blending regions extending from said first and second rotational constraints into said transform volume; and

wherein said means for applying the rotational transform comprises means for reducing a magnitude of the rotational transform within said first and second rotational blending regions respectively to cause continuity of shape between modified portions of the representation of the appliance within said transform volume and un-modified portions of the representation of the appliance outside said transform volume.

60. The apparatus of claim **59** wherein said means for reducing said magnitude of the rotational transform comprises means for applying a rotational transform having:

substantially zero magnitude at said first and second rotational constraints; and

a magnitude that progressively increases with rotational displacement into said transform volume to reach a full rotational transform magnitude beyond said first and second rotational blending regions respectively.

61. The apparatus of claim **59** wherein said means for identifying said first and second rotational blending regions comprises means for receiving operator input defining a rotational extent of said first and second rotational blending regions into the transform volume.

62. The apparatus of claim **59** wherein said means for identifying said first and second rotational blending regions comprises:

means for receiving operator input of a no-blending zone located between said first and second rotational constraints, said no-blending zone defining an angular extent of the transform volume about said rotational axis within which a full magnitude of the rotational transform is to be applied, and wherein said first and second rotational blending regions respectively comprise portions of the transform volume outside said no-blending zone.

63. The apparatus of claim **49** further comprising means for receiving operator input of a desired rotational magnitude and direction of the rotational transform to be applied to said portion of the three-dimensional representation of the appliance within said transform volume.

64. The apparatus of claim **63** further comprising:

means for defining a reference plane oriented orthogonal to the rotational axis and intersecting the appliance representation;

means for displaying a two-dimensional view of an intersection between the three dimensional representation of the appliance and said reference plane;

wherein said means for receiving said operator input of said desired magnitude and direction of the rotational transform to be applied comprises:

means for receiving an operator selection of a reference point on said reference plane; and

means for receiving operator input of a desired rotational displacement of said reference point.

65. The apparatus of claim **64** further comprising means for displaying a modified shape of said intersection in said two-dimensional view.

66. The apparatus of claim **49** wherein said means for applying the rotational transform comprises :

means for determining an angular displacement to be applied to each input coordinate in the input plurality of coordinates; and

means for generating a rotational transformation matrix for the input coordinate, said rotational transform matrix including elements operable to transform said input coordinate into an output coordinate that is angularly displaced from said input coordinate by said angular displacement about the rotational axis.

67. The apparatus of claim **66** wherein the input plurality of coordinates are defined in a first Cartesian coordinate system and further comprising means for generating a modeling matrix having elements operable to transform input coordinates between said first coordinate system and a second Cartesian coordinate system, said second coordinate system having an origin located on said rotational axis, a first axis aligned with said rotational axis, and second and third axes orthogonal to said rotational axis, and wherein said means for determining said angular displacement comprises:

means for determining a corresponding coordinate of said input coordinate in said second coordinate system; and

means for determining an angular displacement of each said corresponding coordinate within a plane defined by said second and third axes of said second coordinate system.

68. The apparatus of claim **49** wherein said means for receiving operator input identifying said coordinate location of said rotational axis comprises means for receiving operator input defining:

coordinates of a three-dimensional line representing a location of the rotational axis with respect to the appliance representation;

a location of a reference plane intersecting the appliance representation and oriented orthogonal to the three-dimensional line; and

a location of an origin point on the reference plane through which the rotational axis passes.

69. The apparatus of claim **68** further comprising means for displaying a three-dimensional representation of said appliance, said reference plane, and said three-dimensional line and wherein said means for receiving said operator input comprises means for receiving pointer signals from a pointing device in communication with the processor circuit, the pointing signals being operable to define desired changes to said coordinates of at least one of said three-dimensional line, said location of said reference plane, and said location of said origin point on said reference plane with respect to said appliance.

70. The apparatus of claim **69** further comprising means for displaying a two-dimensional view of the intersection of the general shape of the appliance with the reference plane and wherein said means for receiving said operator input comprises means for receiving pointer signals from said pointing device, the pointing signals being operable to define desired changes to said origin point on said reference plane.

71. The apparatus of claim **49** wherein said means for applying the rotational transform to the portion of the three-dimensional representation of the appliance within the transform volume to produce an output plurality of coordinates comprises:

means for producing modified coordinates representing said modified shape of the appliance within said transform volume; and

means for resampling said modified coordinates and said un-modified coordinates outside said transform volume to produce said output plurality of coordinates representing said modified appliance representation.

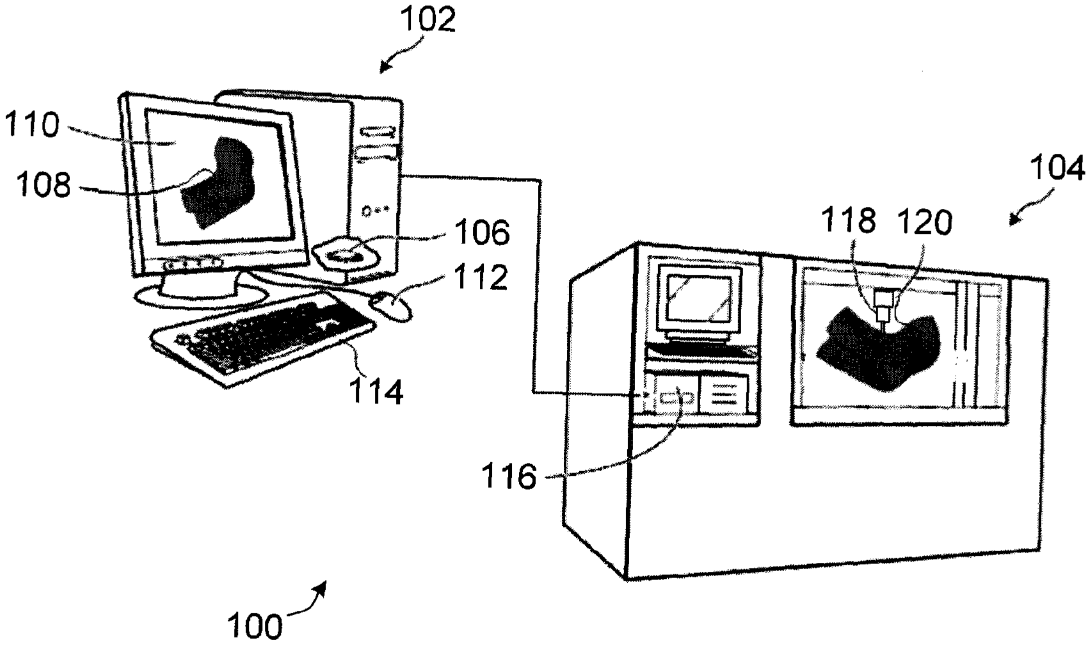

102
110
108
106
112
114
104
118 120
116
100

FIG. 1

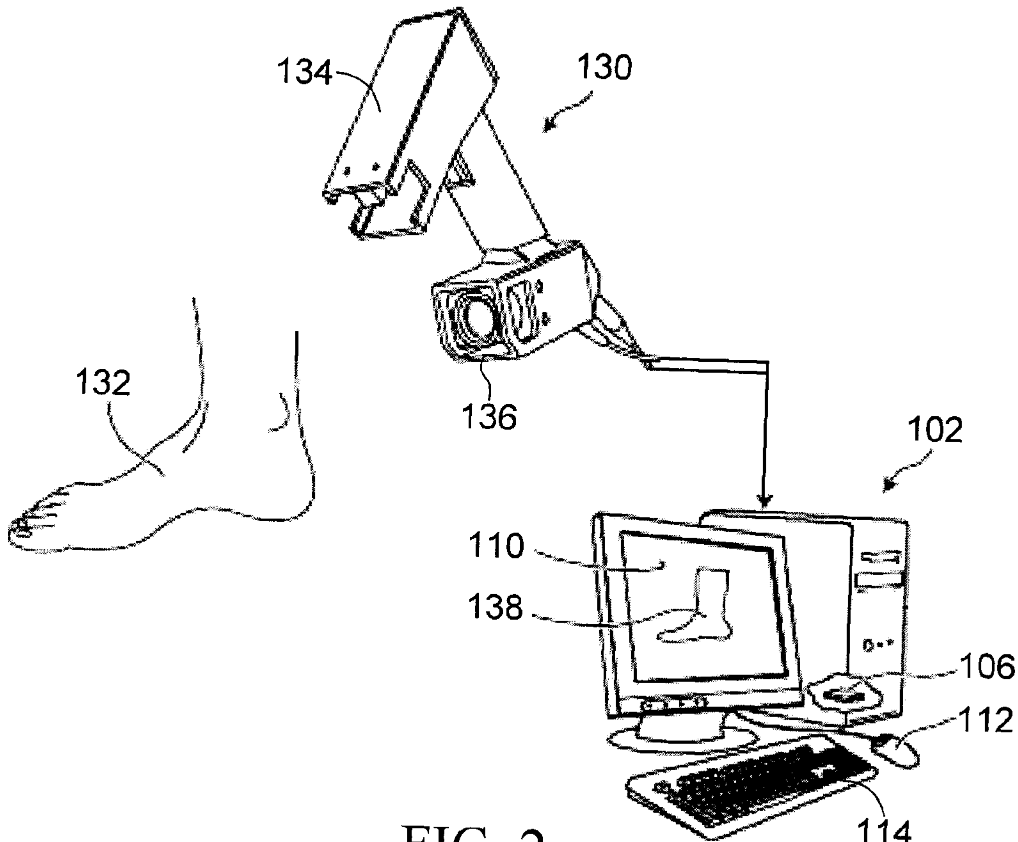

134
130
132
136
102
110
138
106
112
114

FIG. 2

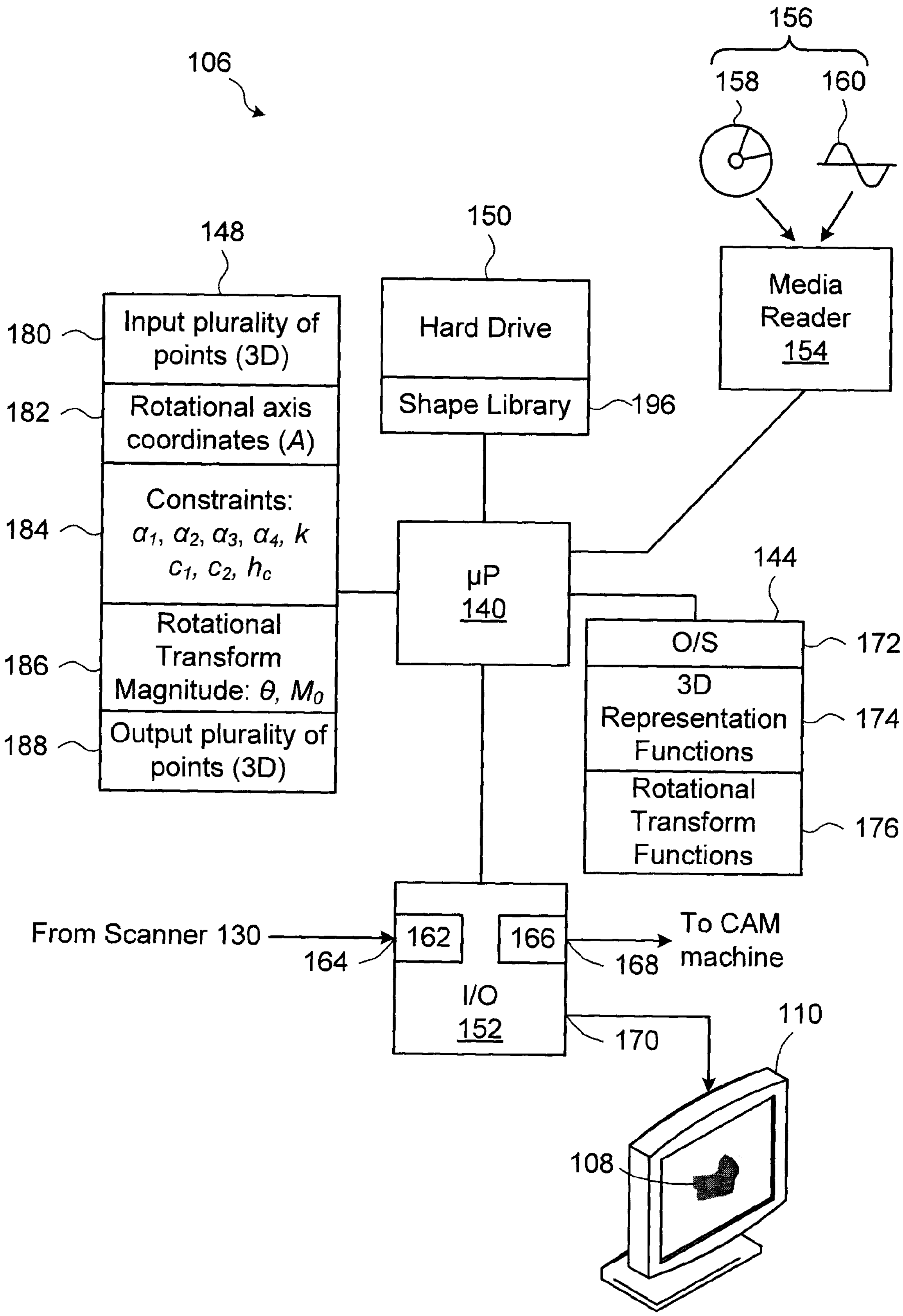

106
156
158
160
148
150
Input plurality of points (3D)
180
Rotational axis coordinates (A)
182
Constraints: α1, α2, α3, α4, k c1, c2, hc
184
Rotational Transform Magnitude: θ, M0
186
Output plurality of points (3D)
188
Hard Drive
Shape Library
196
Media Reader 154
μP 140
144
O/S
172
3D Representation Functions
174
Rotational Transform Functions
176
From Scanner 130
164
162
166
168
To CAM machine
I/O 152
170
110
108

FIG. 3

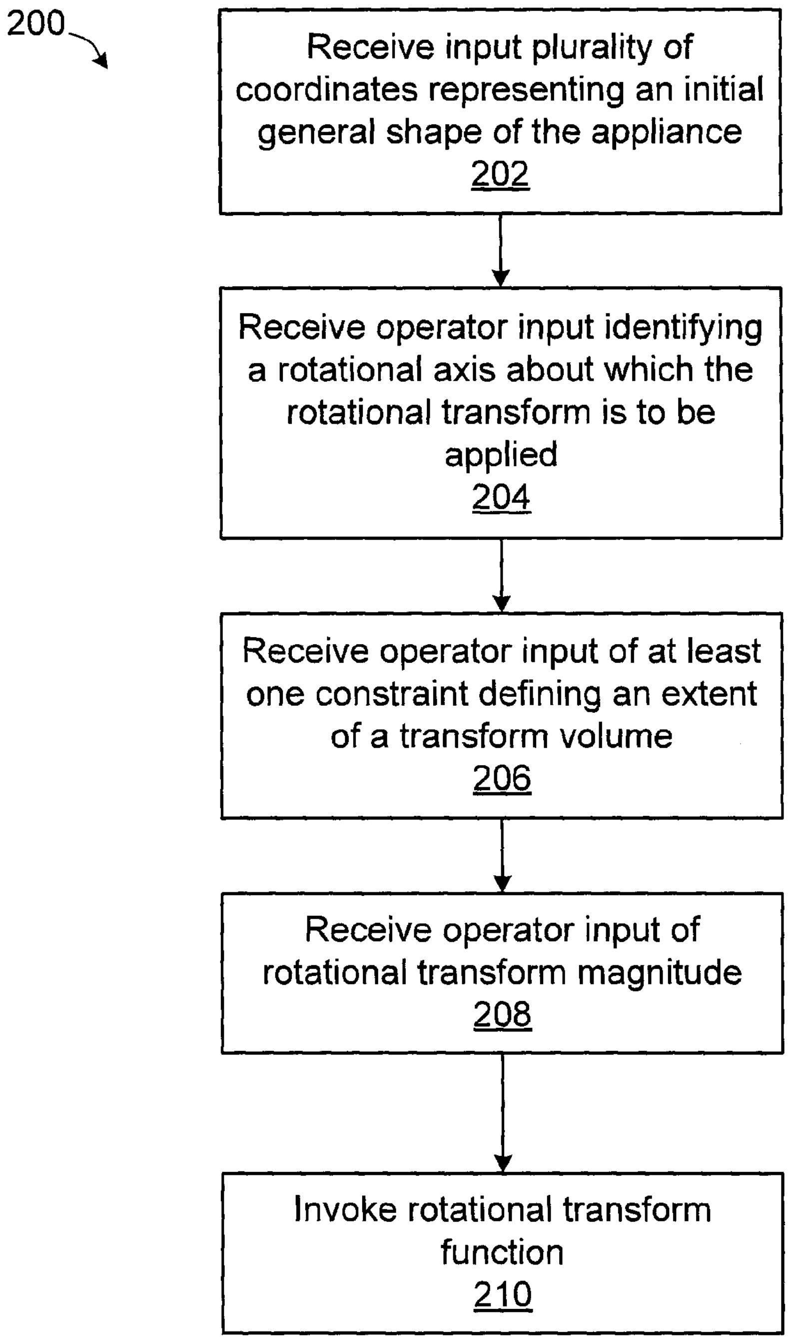

200
Receive input plurality of coordinates representing an initial general shape of the appliance
202
Receive operator input identifying a rotational axis about which the rotational transform is to be applied
204
Receive operator input of at least one constraint defining an extent of a transform volume
206
Receive operator input of rotational transform magnitude
208
Invoke rotational transform function
210

FIG. 4

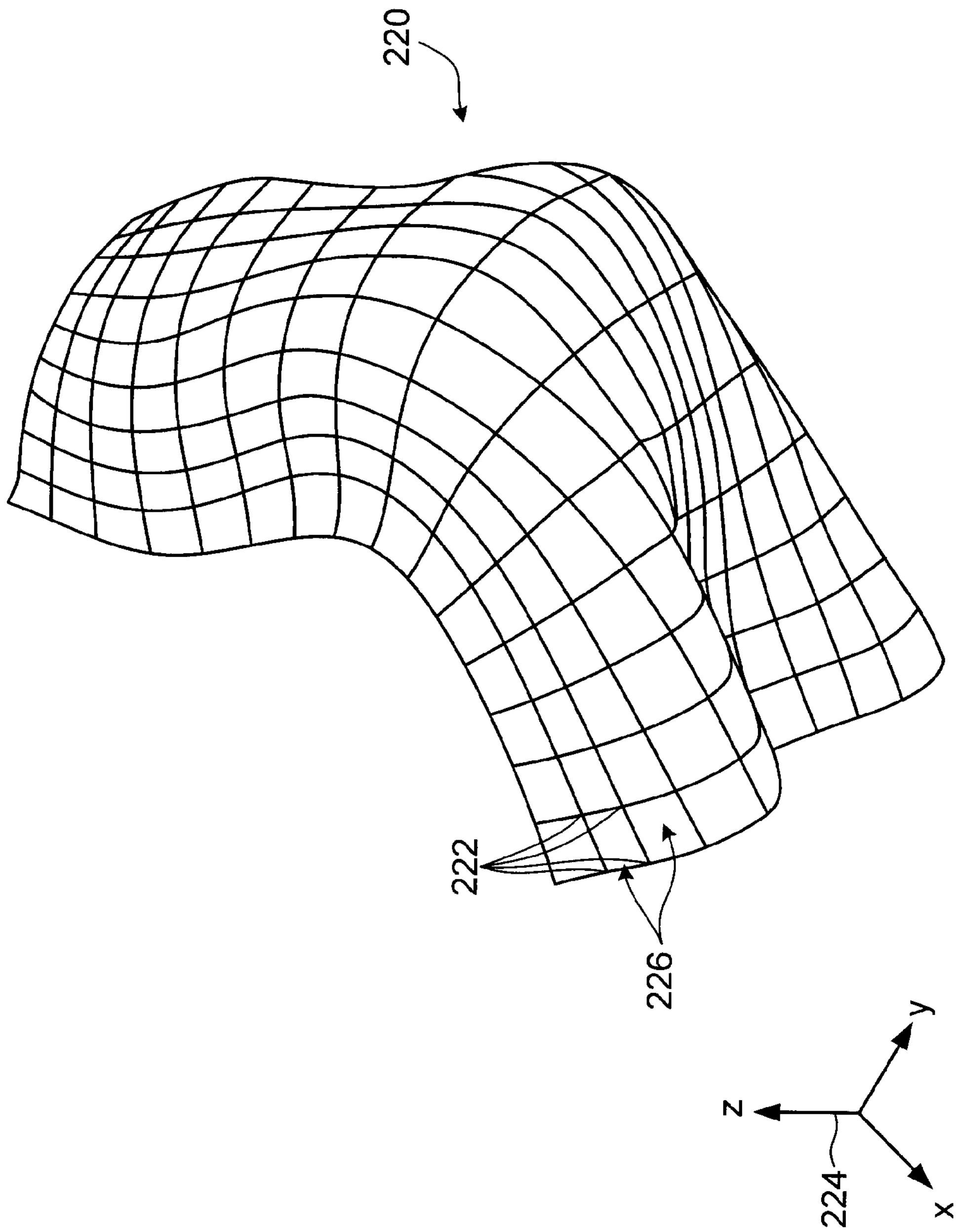
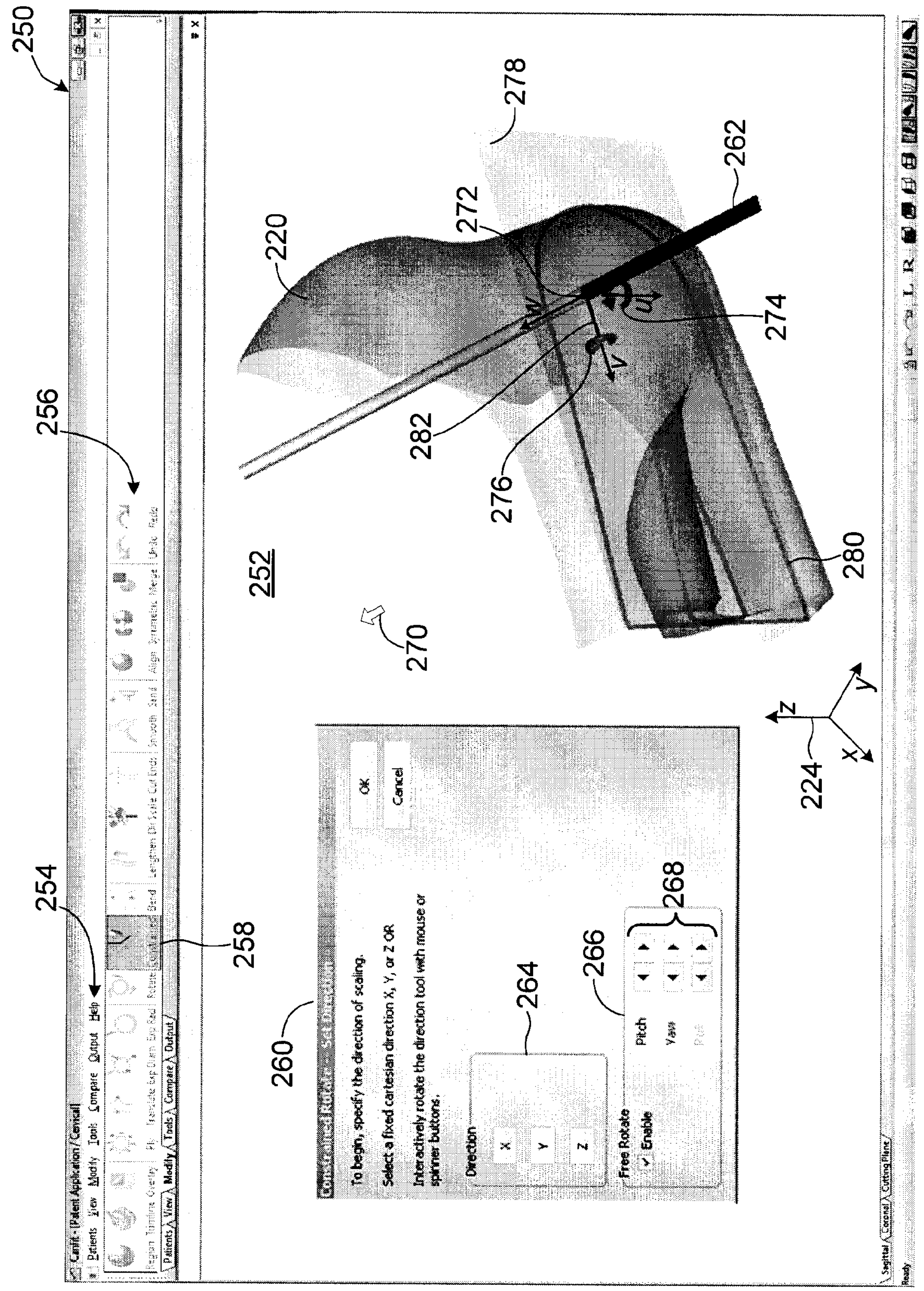


FIG. 5

5/11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282
224

FIG. 6

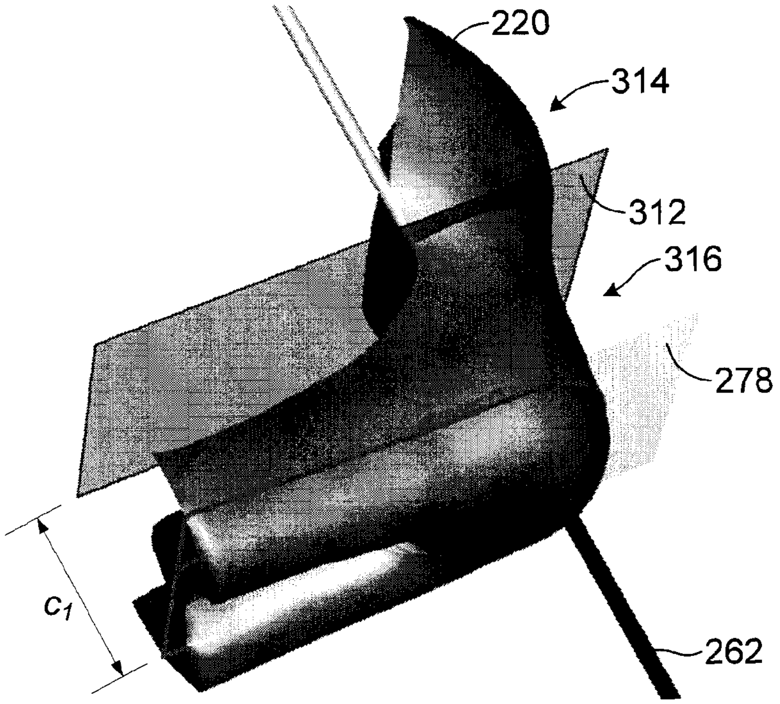


FIG. 7

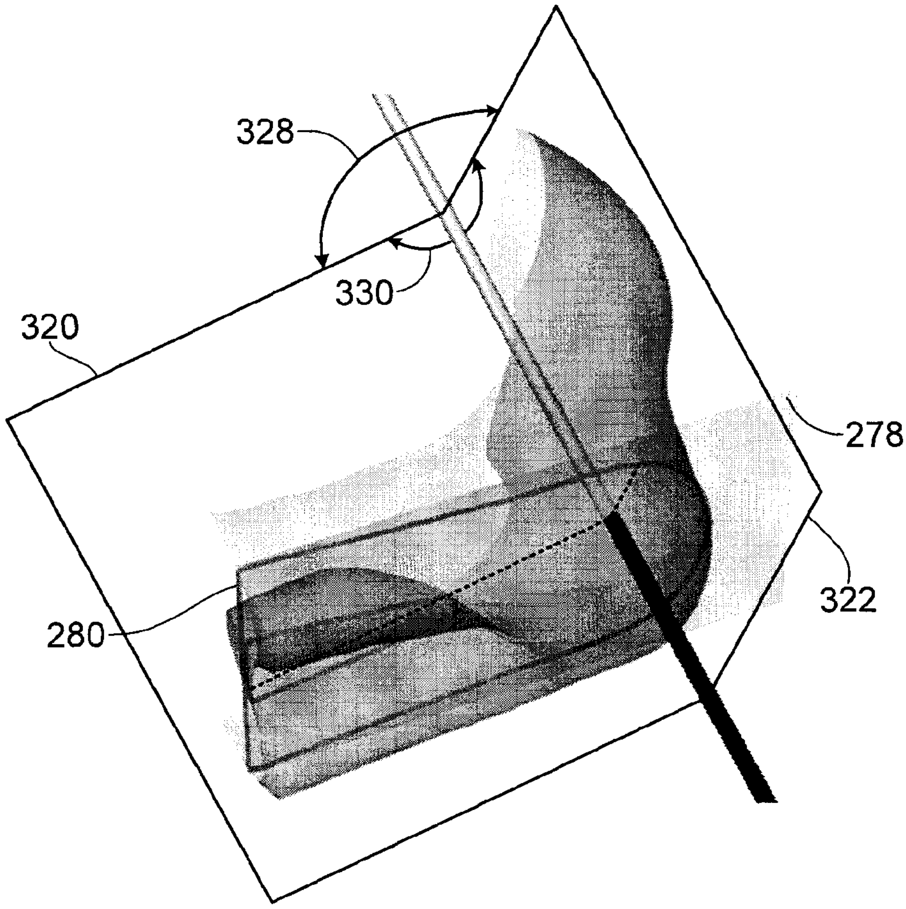
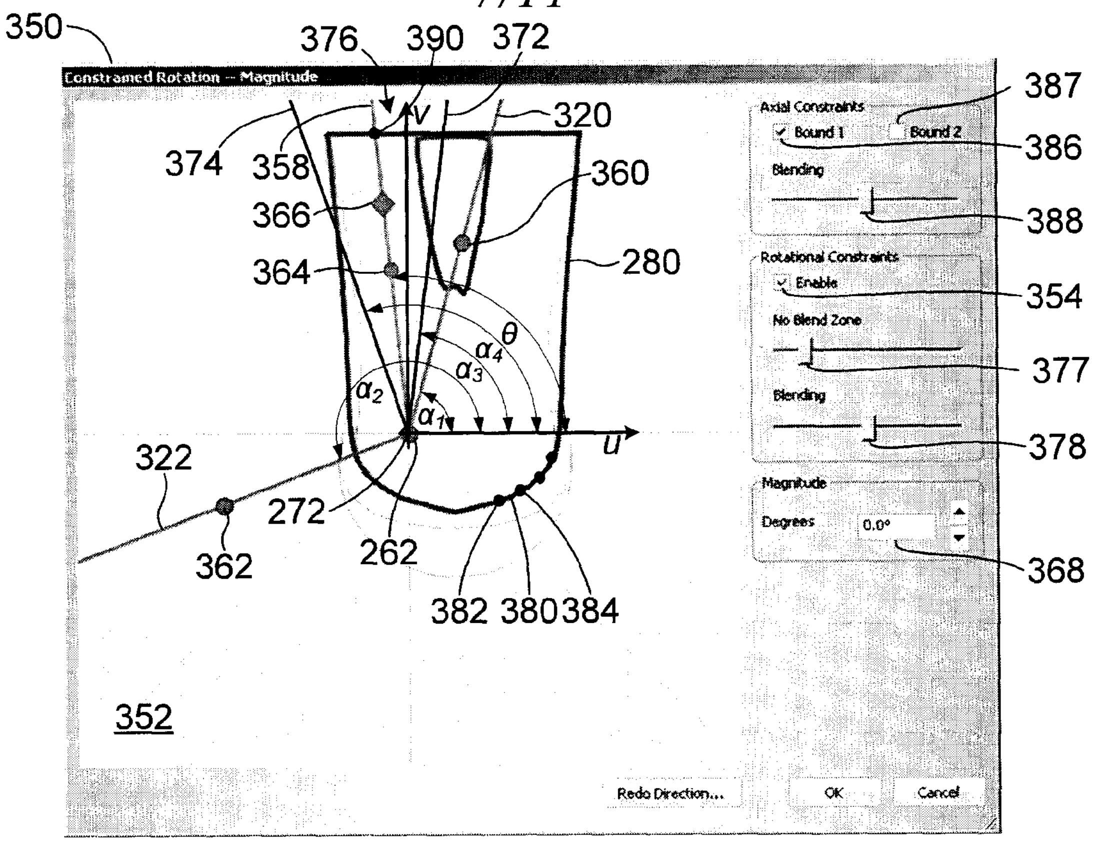
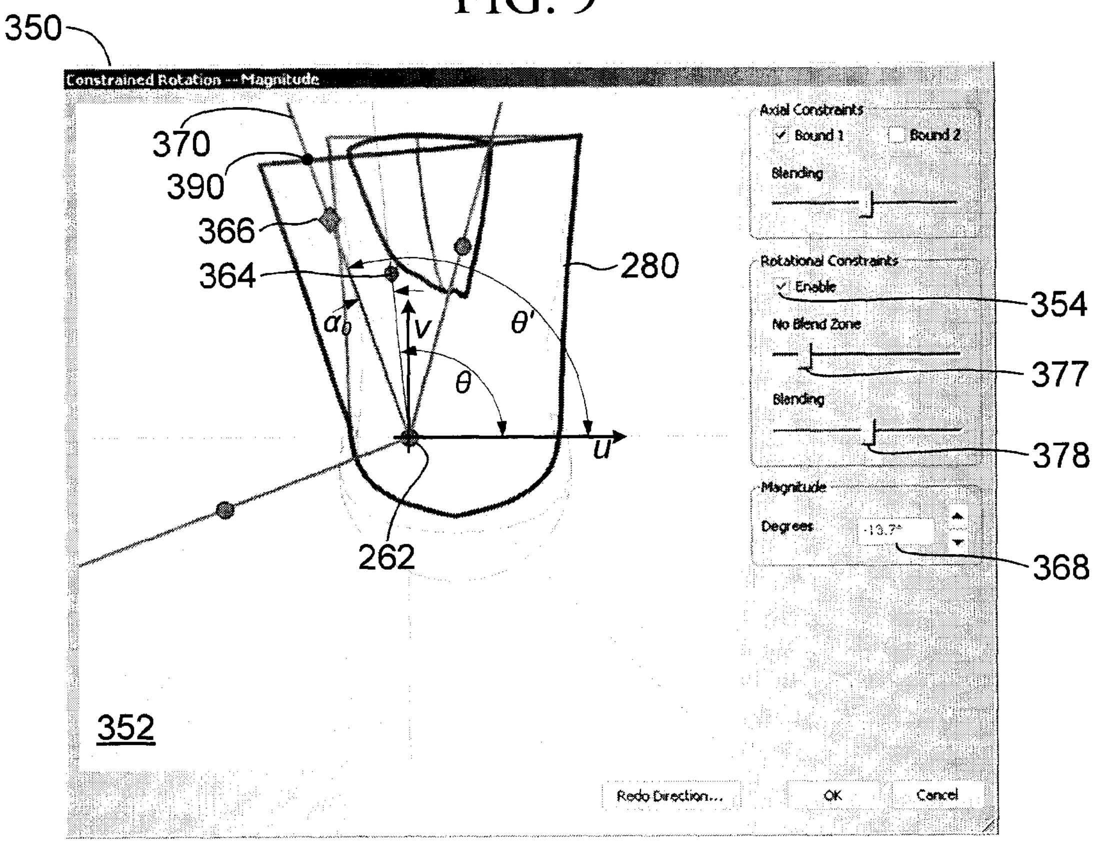


FIG. 8



350
376
390
372
Constrained Rotation -- Magnitude
374
358
v
320
366
360
364
280
θ
α4
α3
α2
α1
u
322
272
262
362
382
380
384
352
387
386
388
354
377
378
368
Axial Constraints
Bound 1
Bound 2
Blending
Rotational Constraints
Enable
No Blend Zone
Blending
Magnitude
Degrees
0.0°
Redo Direction...
OK
Cancel

FIG. 9



350
Constrained Rotation -- Magnitude
370
390
366
364
280
α0
v
θ'
θ
u
262
352
354
377
378
368
Axial Constraints
Bound 1
Bound 2
Blending
Rotational Constraints
Enable
No Blend Zone
Blending
Magnitude
Degrees
-13.7°
Redo Direction...
OK
Cancel

FIG. 10

400

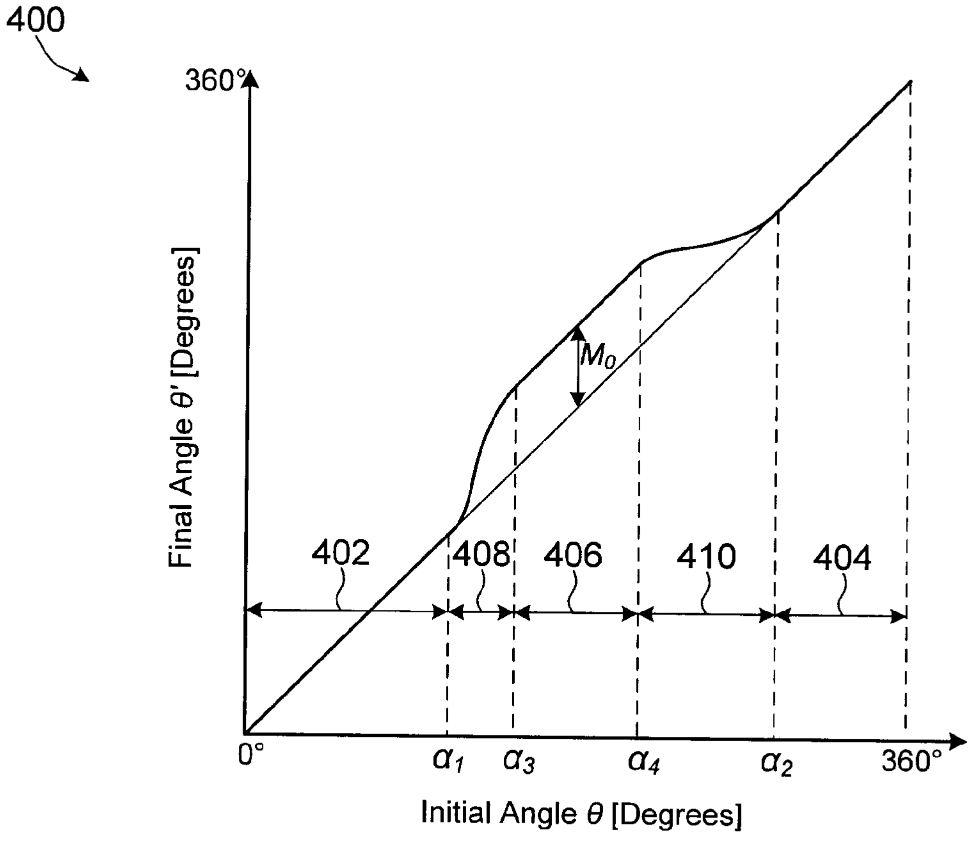

360°
Final Angle θ' [Degrees]
M_0
402
408
406
410
404
0°
α_1
α_3
α_4
α_2
360°
Initial Angle θ [Degrees]

FIG. 11

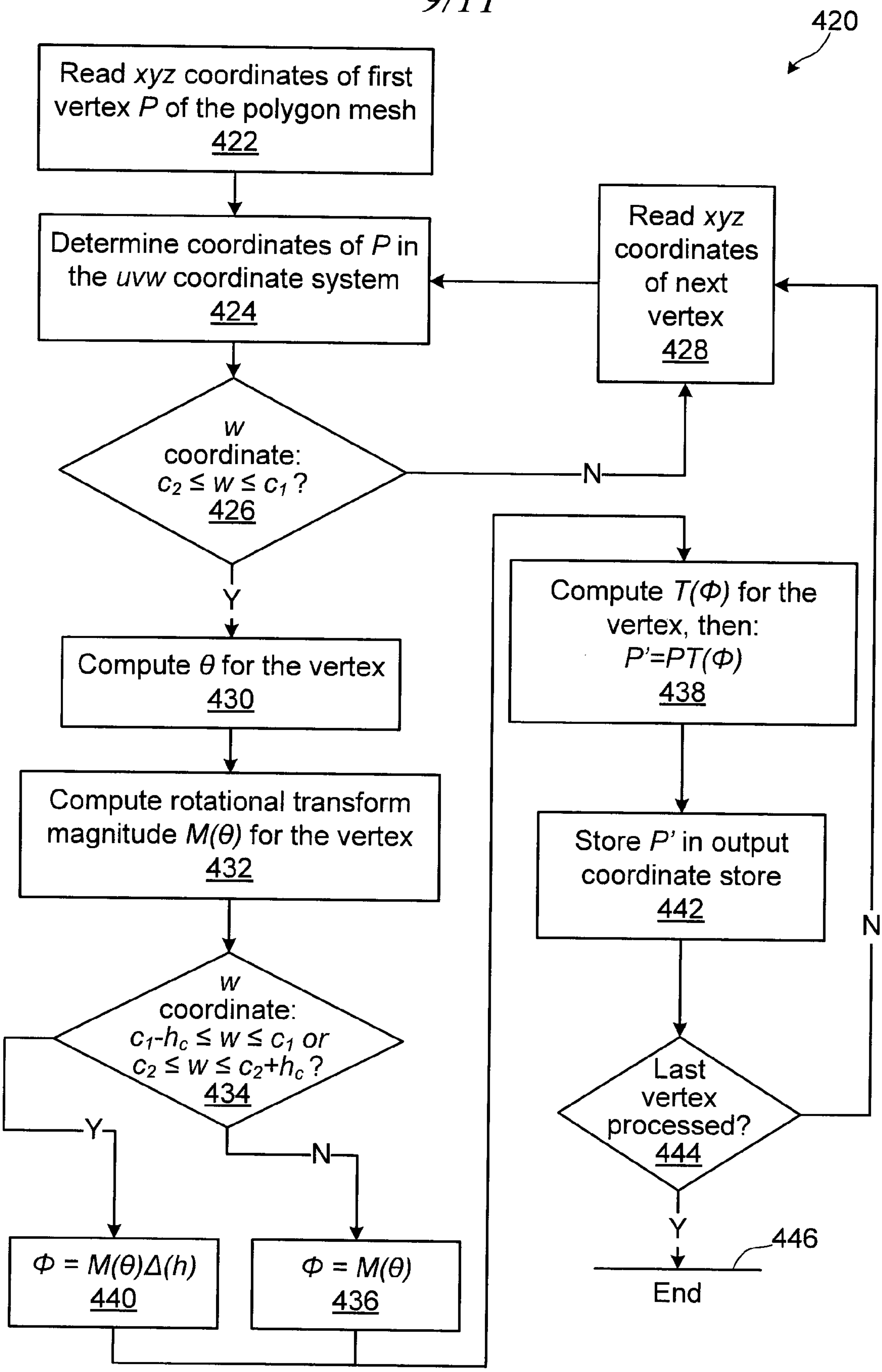
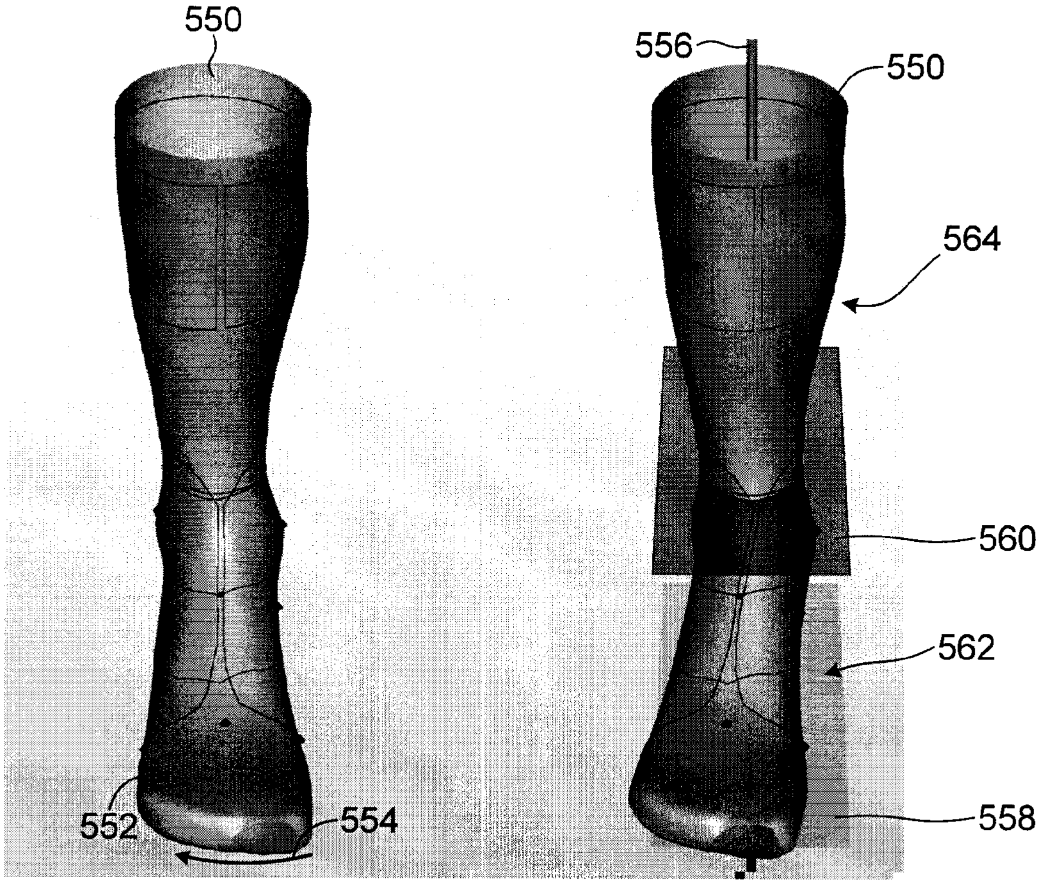

420
Read xyz coordinates of first vertex P of the polygon mesh 422
Determine coordinates of P in the uvw coordinate system 424
w coordinate: c2 ≤ w ≤ c1 ? 426
N
Read xyz coordinates of next vertex 428
Y
Compute θ for the vertex 430
Compute rotational transform magnitude M(θ) for the vertex 432
w coordinate: c1-hc ≤ w ≤ c1 or c2 ≤ w ≤ c2+hc ? 434
Y
N
Φ = M(θ)Δ(h) 440
Φ = M(θ) 436
Compute T(Φ) for the vertex, then: P'=PT(Φ) 438
Store P' in output coordinate store 442
Last vertex processed? 444
N
Y
446
End

FIG. 12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558

FIG. 13

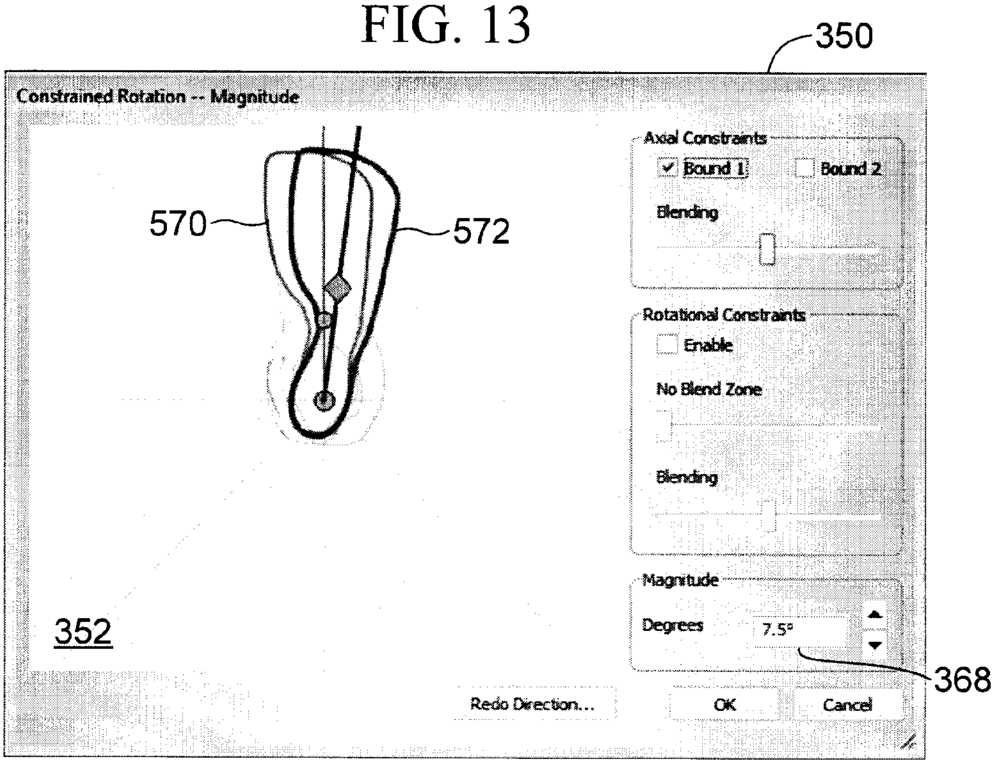
350
Constrained Rotation -- Magnitude
570
572
Axial Constraints
Bound 1
Bound 2
Blending
Rotational Constraints
Enable
No Blend Zone
Blending
Magnitude
Degrees
7.5°
352
368
Redo Direction...
OK
Cancel

FIG. 14

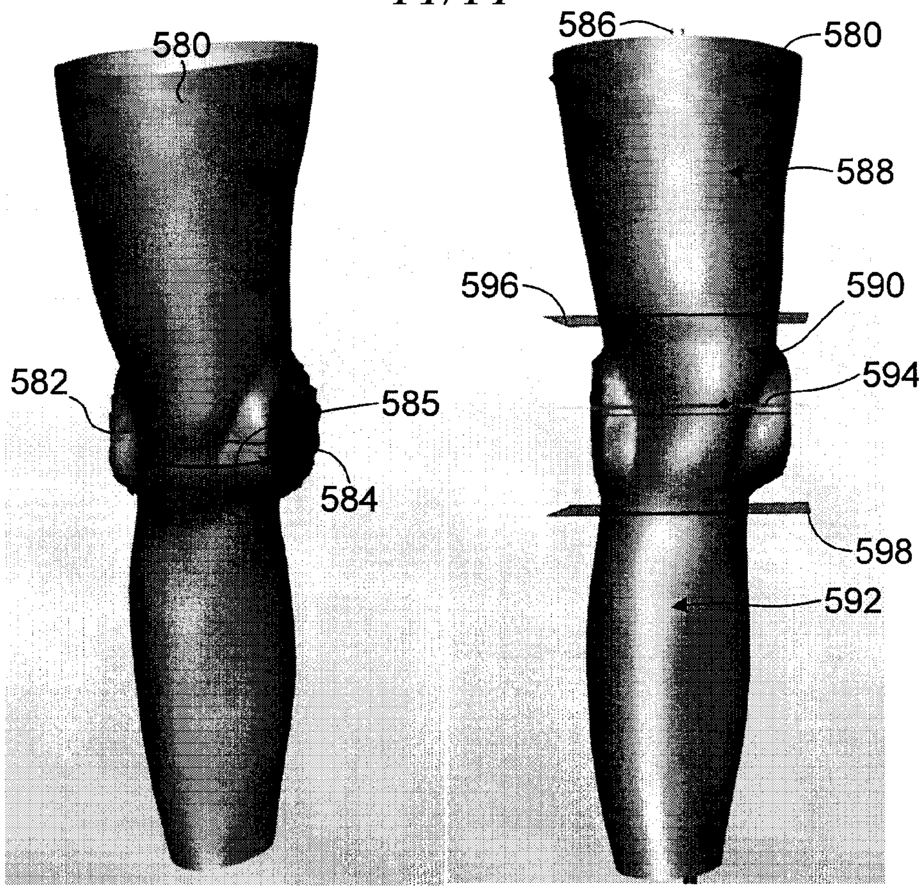
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FIG. 15

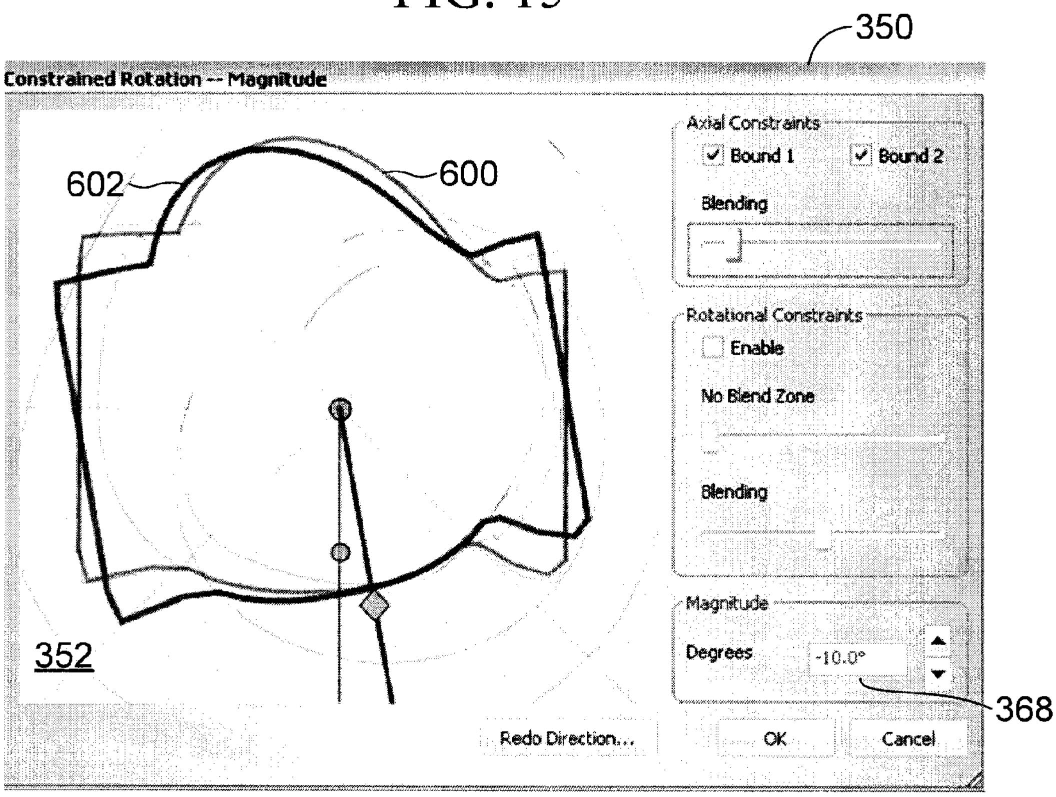
350
Constrained Rotation -- Magnitude
602
600
352
Axial Constraints
Bound 1
Bound 2
Blending
Rotational Constraints
Enable
No Blend Zone
Blending
Magnitude
Degrees
-10.0°
368
Redo Direction...
OK
Cancel

FIG. 16

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2009/000417

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***G06T 17/40*** (2006.01) , ***G05B 19/4099*** (2006.01) , *A61F 5/01* (2006.01) , *A61F 2/76* (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) , ***G05B 19/4099*** (2006.01) , *A61F 5/01* (2006.01) , *A61F 2/76* (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, EPODOC, TXTE, IEEE-Xplore, Google Scholar
Keywords: rotation, transform, matrix, volume, CAM, orthosis, orthotics, prosthesis

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO2009015455 A1 (SABISTON, R.M.) 5 February 2009 (05-02-2009) See abstract, page 1, line 10 to page 2, line 2; page 2, line 16 to page 6, line 8; page 20, lines 3-11, page 21, lines 6-23; page 26, lines 17-26, fig. 2, 7.	1-71
Y	WO2006110895 A2 (BEHZAD, D.) 19 October 2006 (19-10-2006) See paragraphs 10, 58, 59, 104, 121, 127.	1-71
A	OBERG, K. et al.: "The CAPOD System - A Scandinavian CAD CAM System for Prosthetic Sockets", Journal of Prosthetics and Orthotics, 1989, vol. 1, no. 3, pp.139-148 See page 140, second paragraph, all page 143, page 145 up to "Clinical Experience and results", and page 147, fifth paragraph.	1, 24, 47-49

[ ] Further documents are listed in the continuation of Box C. [x] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 December 2009 (09-12-2009)	16 December 2009 (16-12-2009)

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Canadian Intellectual Property Office
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50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 001-819-953-2476

Authorized officer
Corneliu Remes (819) 934-2675

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(Continuation of the Patent Family Annex)

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