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(54) **SYSTEM AND METHOD FOR HUMAN MOTION DETECTION AND TRACKING**

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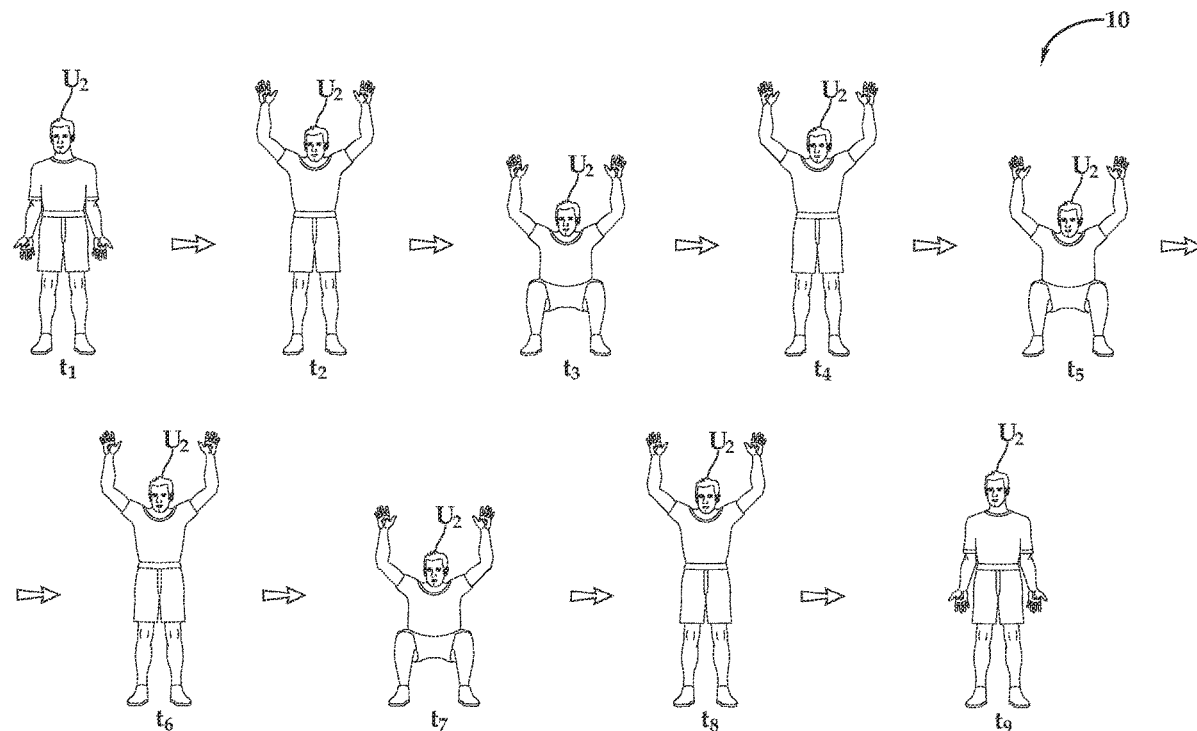
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(57) **ABSTRACT**

A system and method for human motion detection and tracking are disclosed. In one embodiment, a smart device having an optical sensing instrument monitors a stage. Memory is accessible to a processor and communicatively coupled to the optical sensing instrument. The system captures an image frame from the optical sensing instrument. The image frame is then converted into a designated image frame format, which is provided to a pose estimator. A two-dimensional dataset is received from the pose estimator. The system then converts, using inverse kinematics, the two-dimensional dataset into a three-dimensional dataset, which includes time-independent static joint positions, and then calculates, using the three-dimensional dataset, the position of each of the respective plurality of body parts in the image frame.



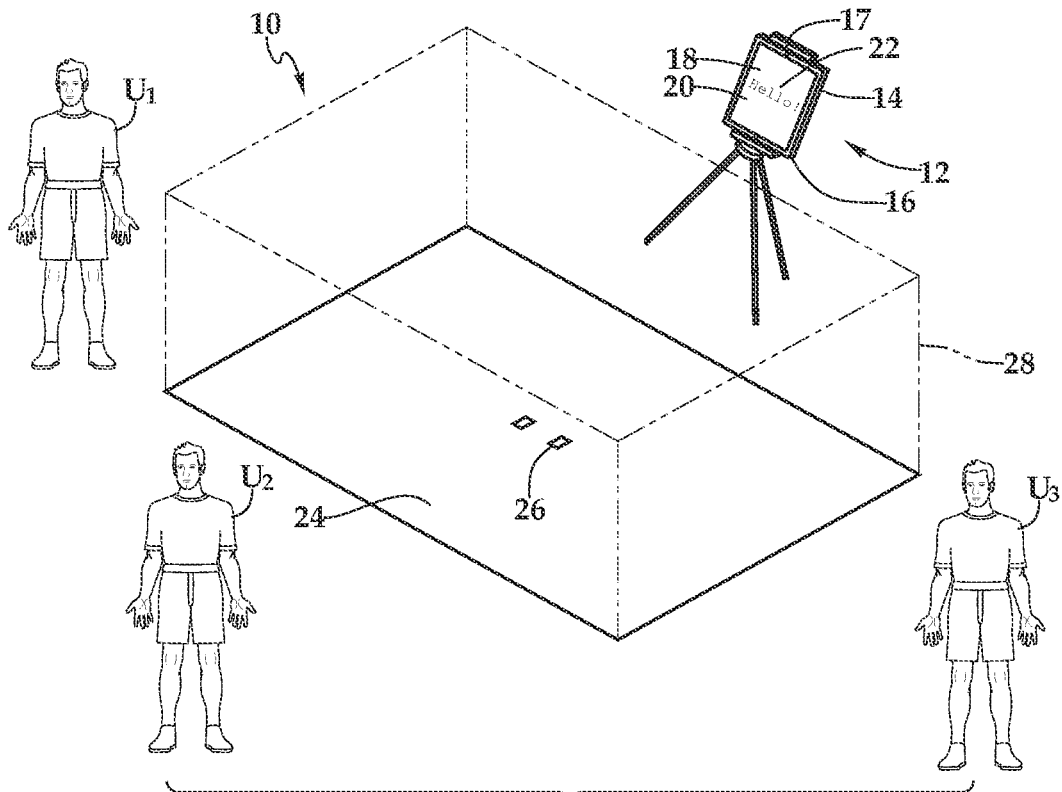


Fig.1A

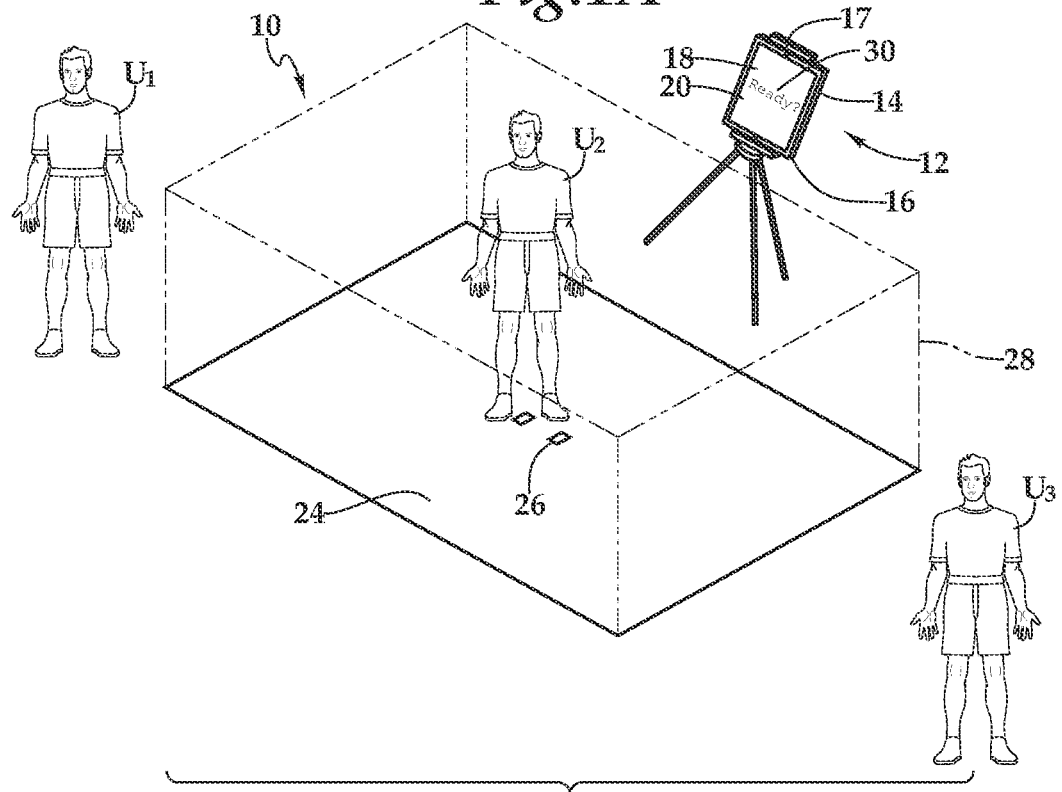
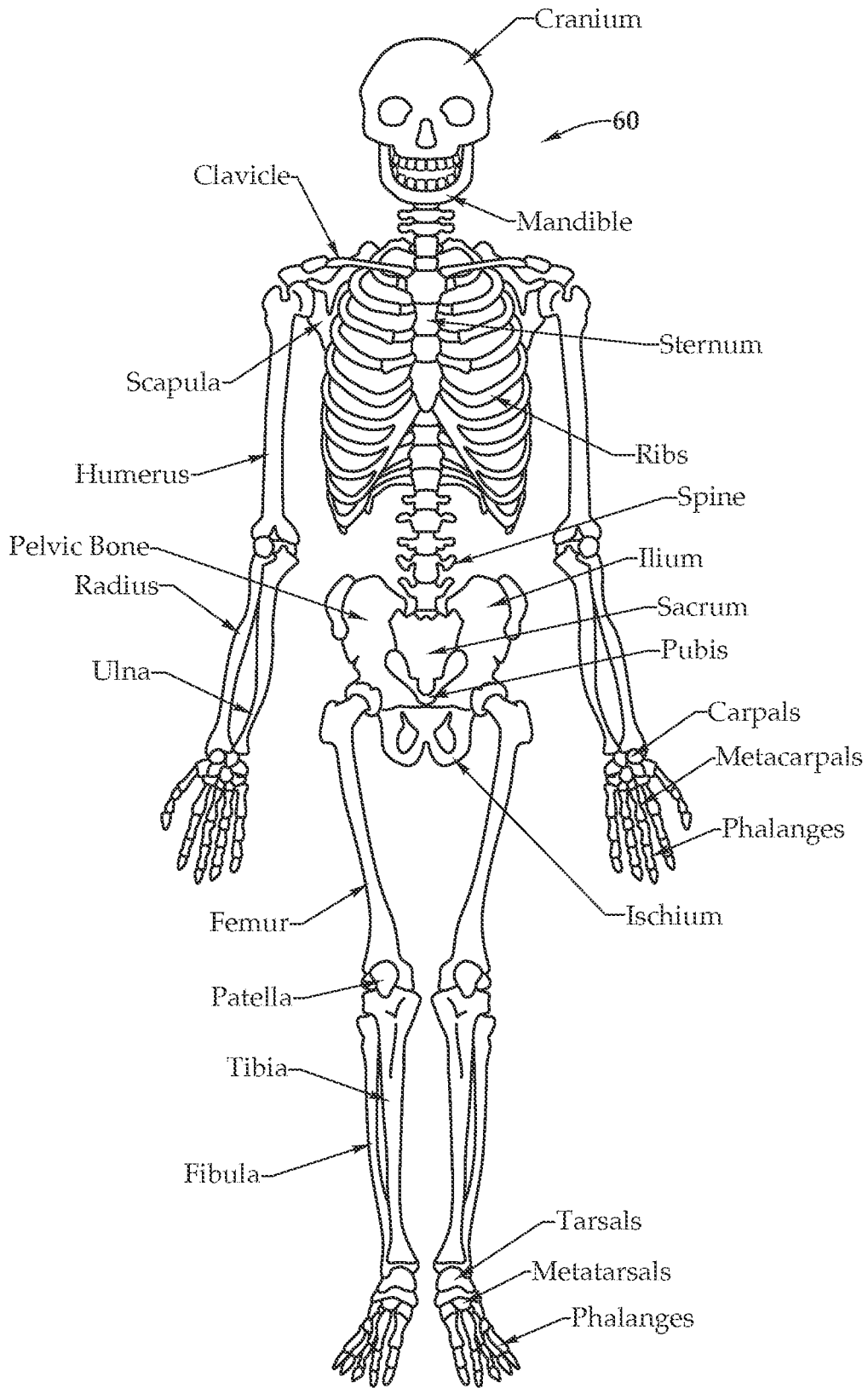


Fig.1B



*Fig.2*

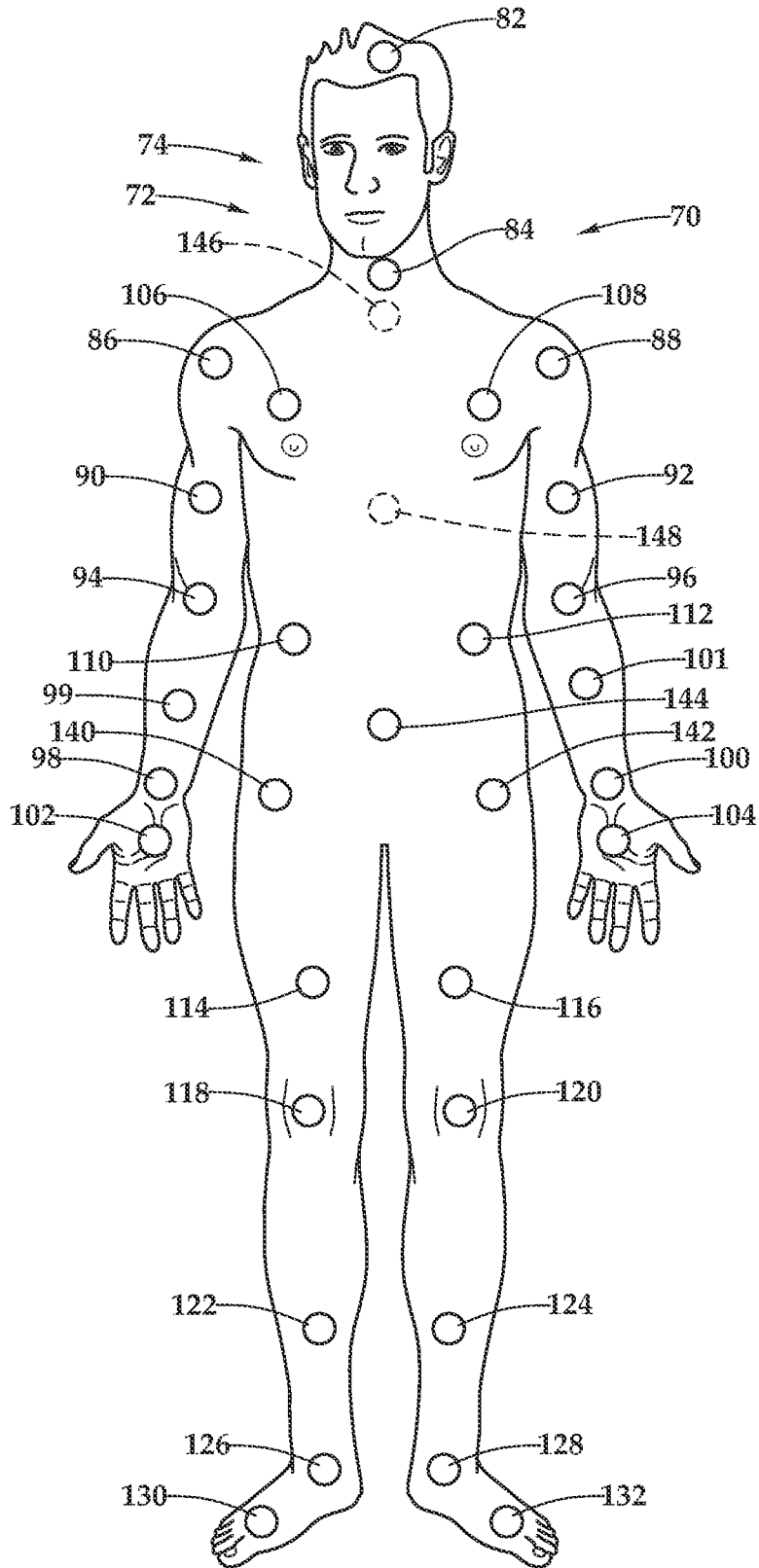
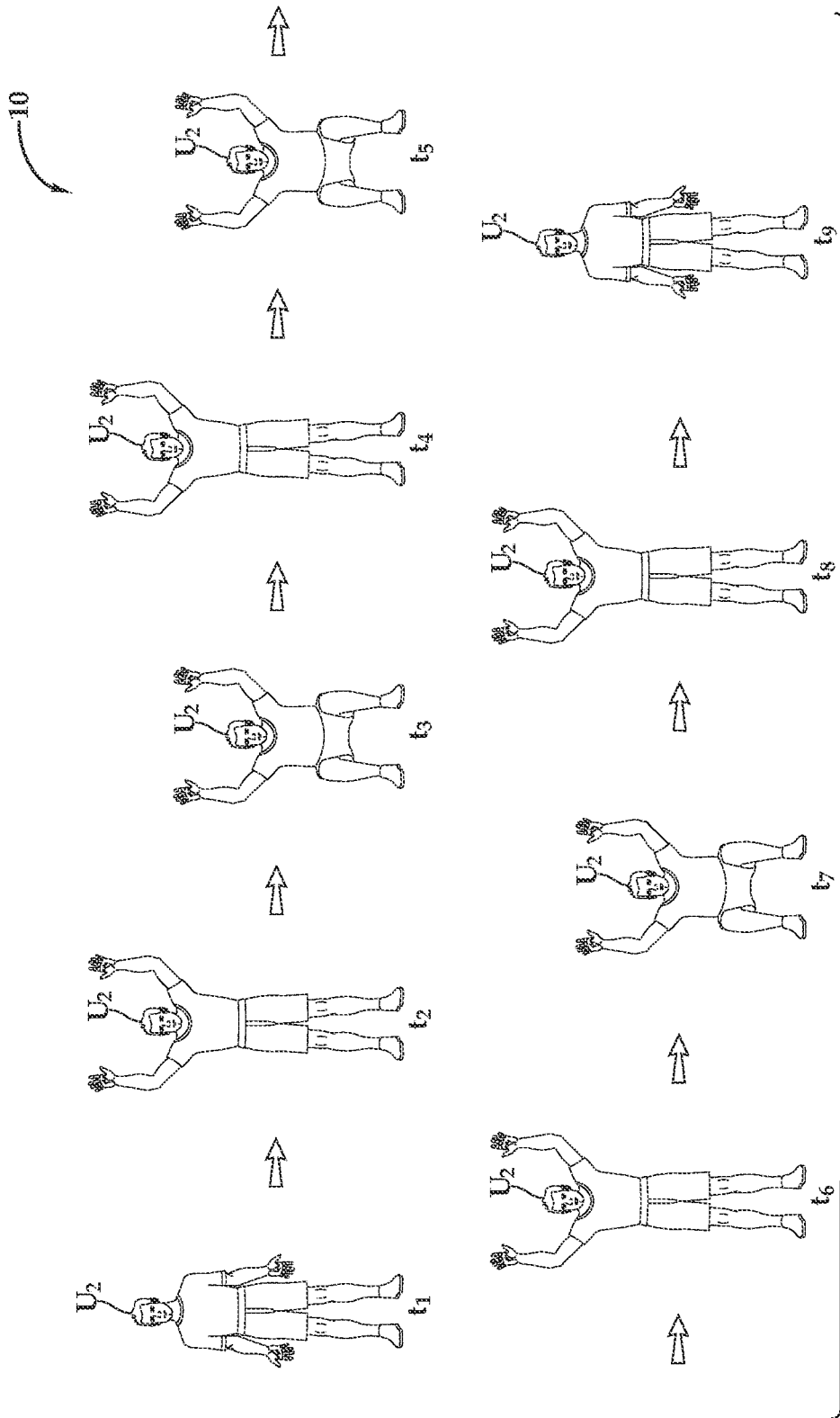


Fig.3



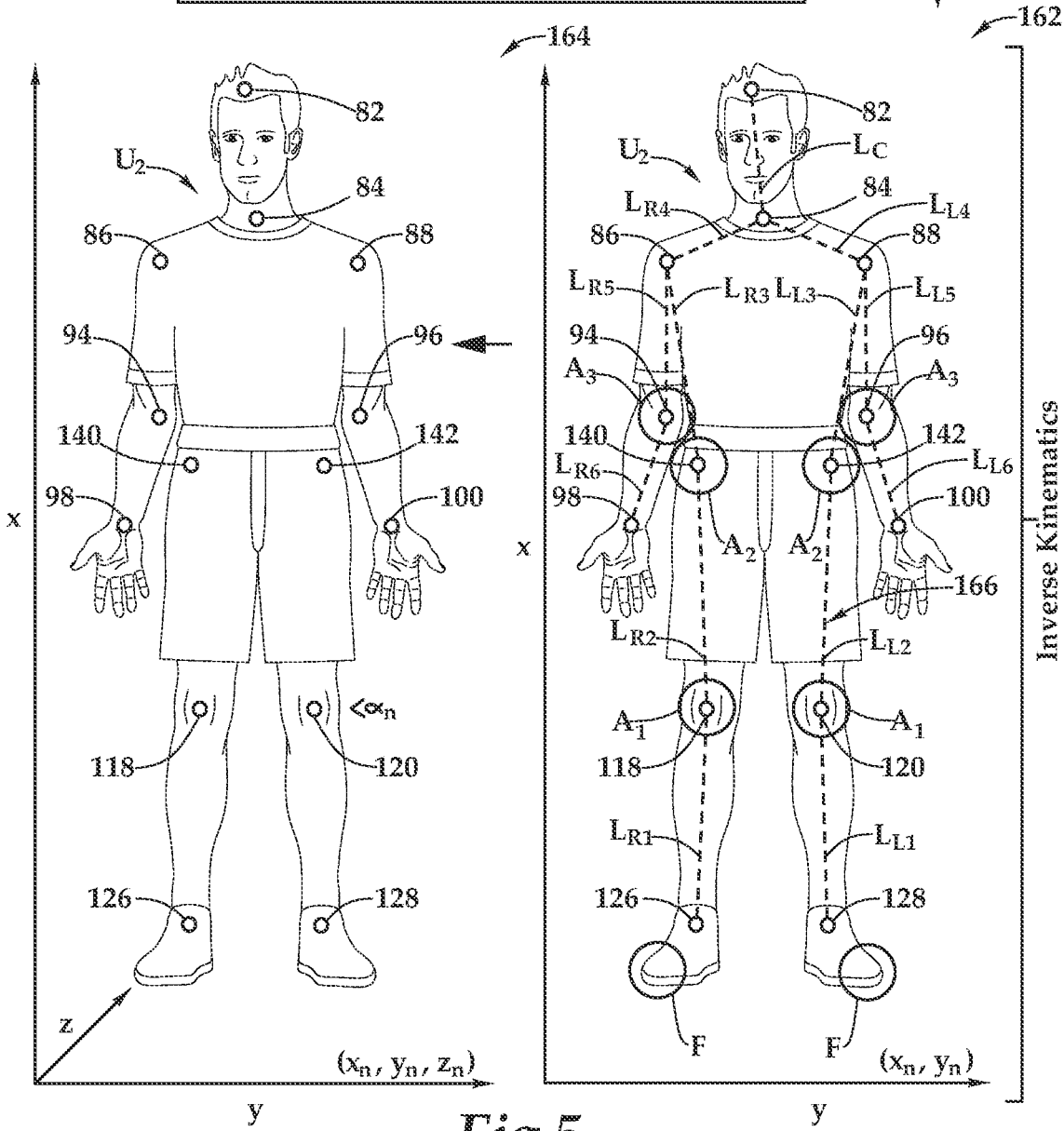
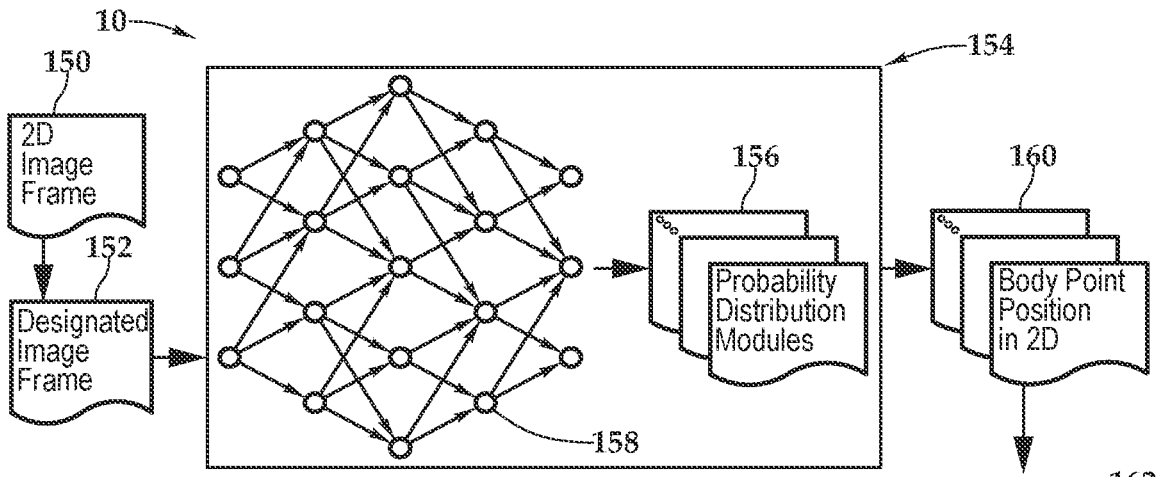


Fig.5

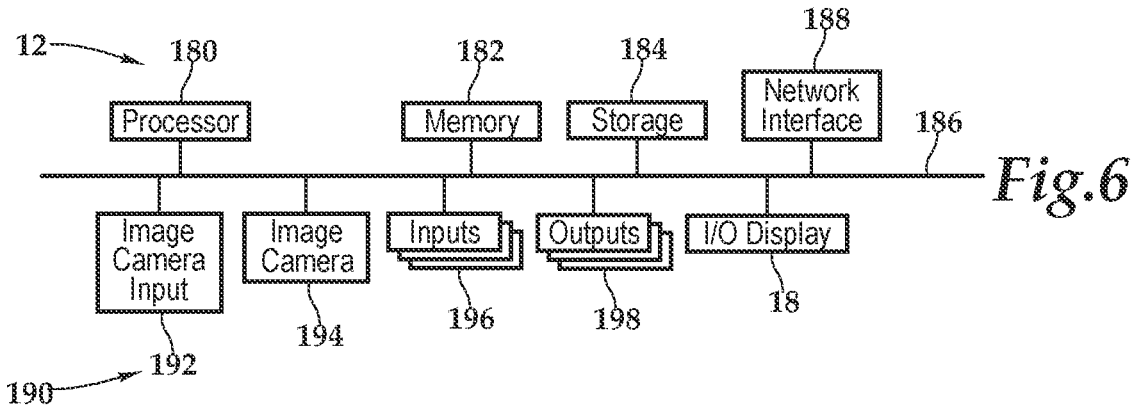


Fig.6

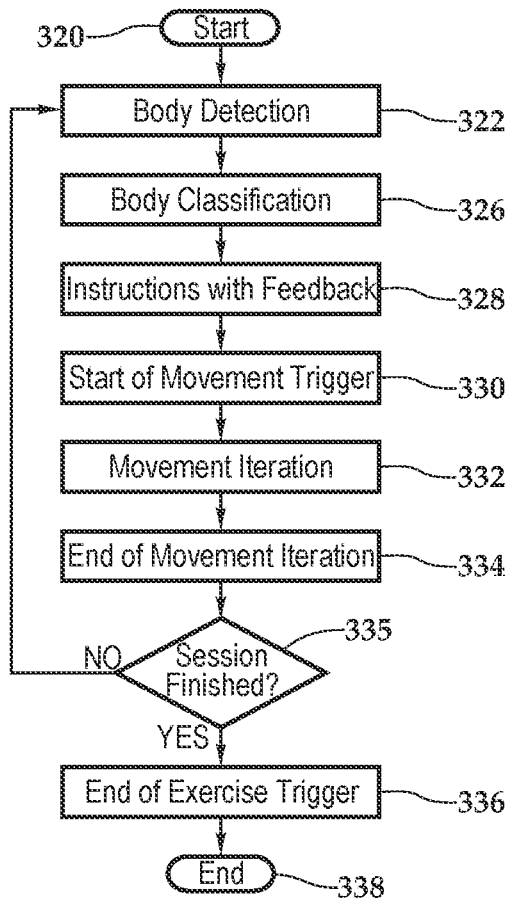


Fig.8

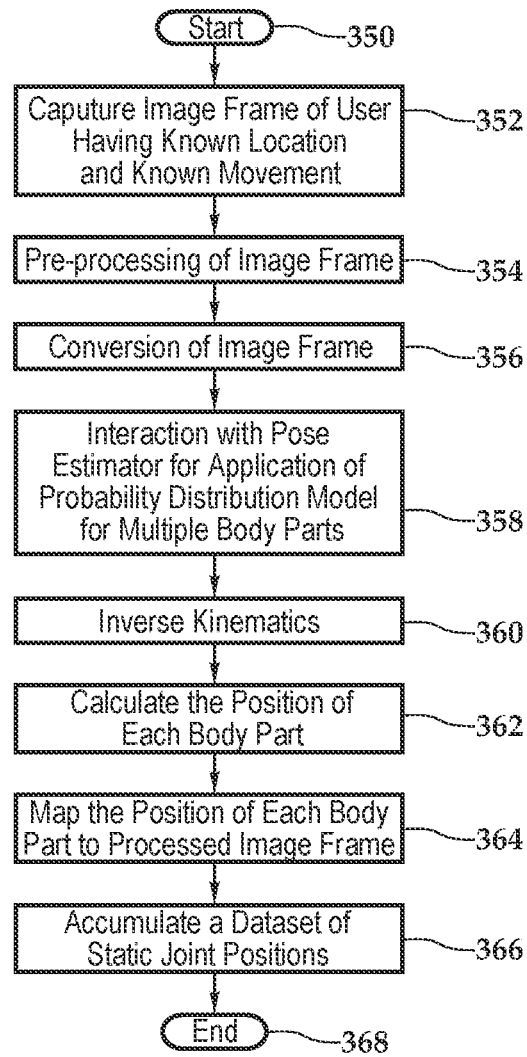


Fig.9

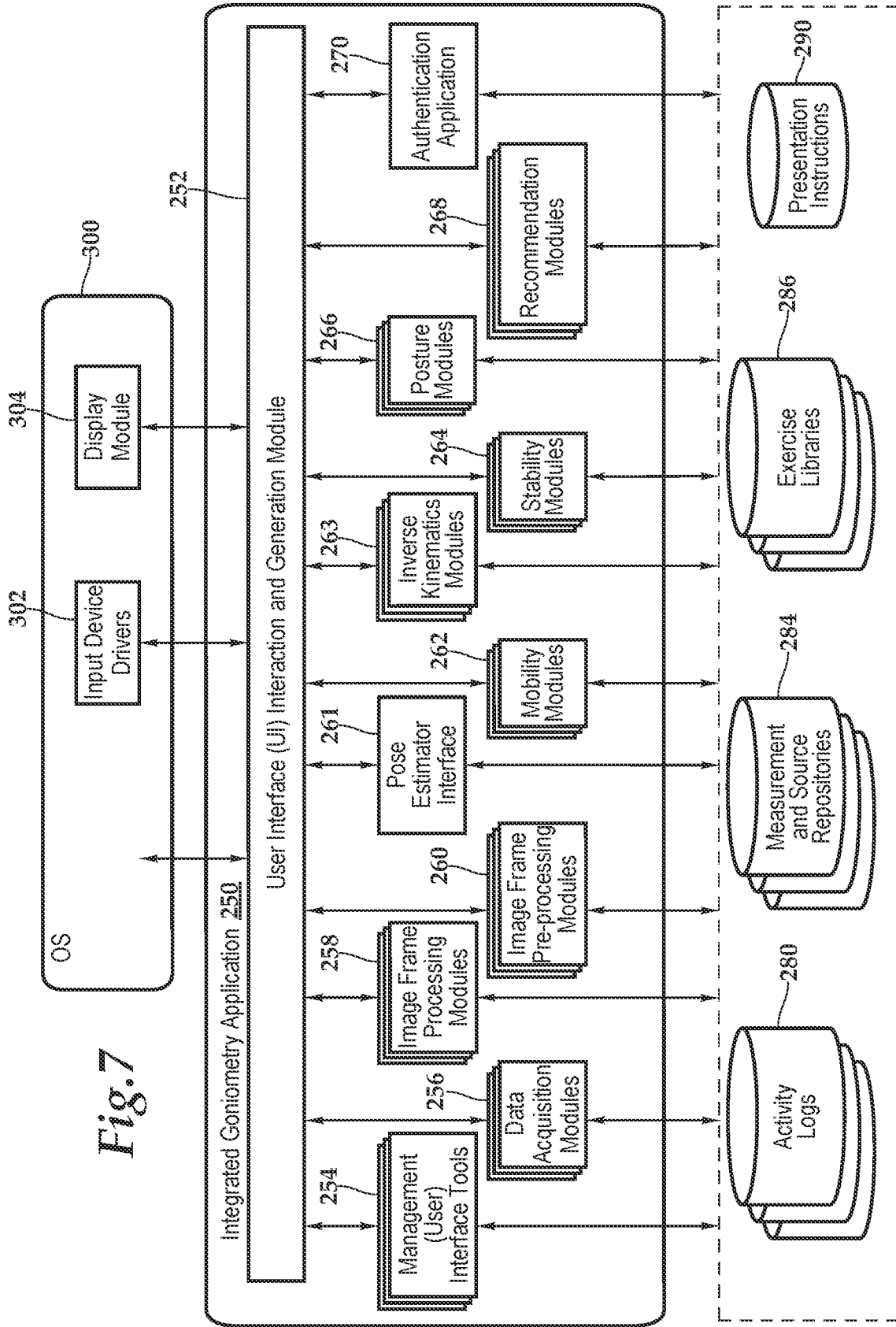


Fig. 7



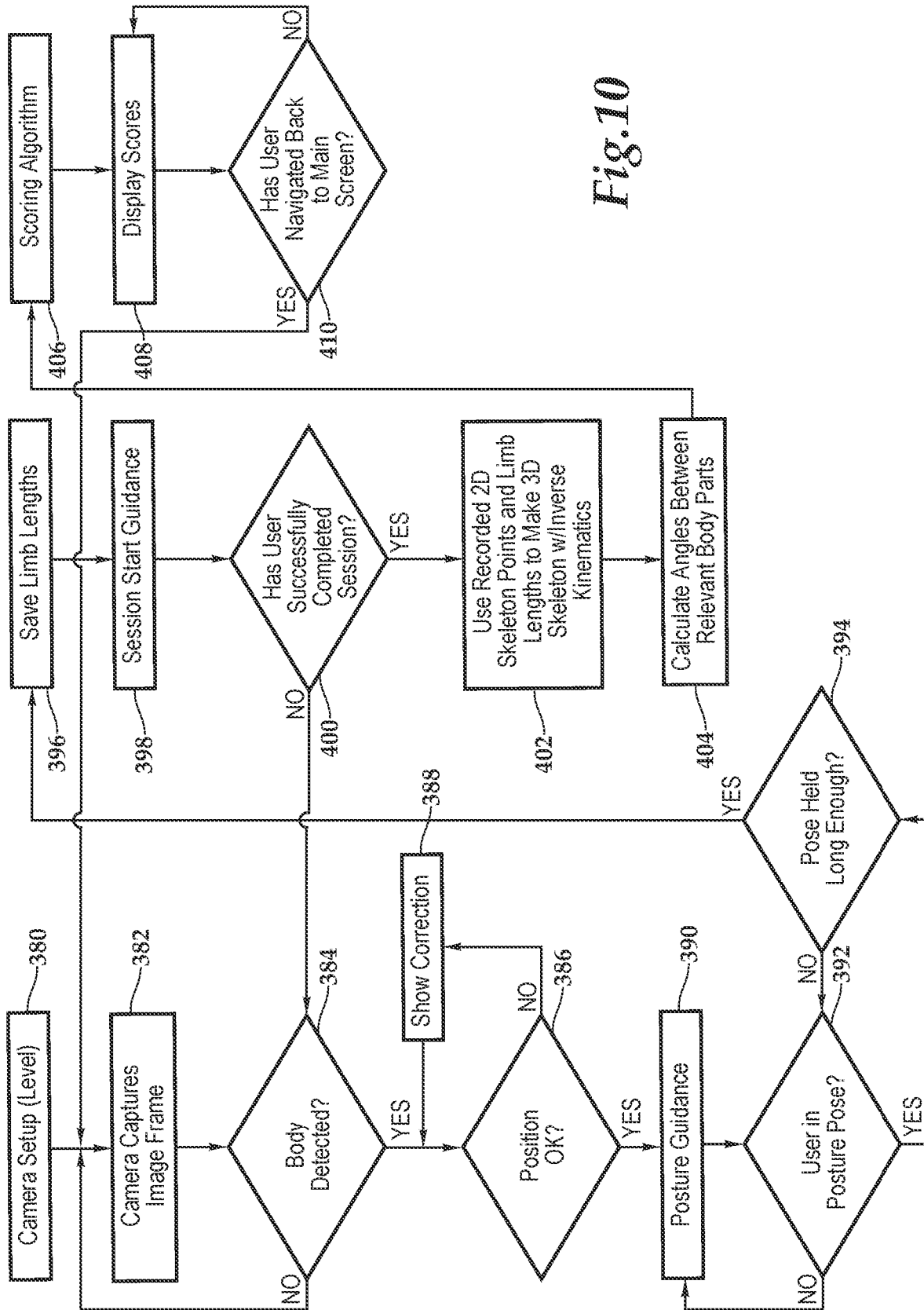


Fig. 10

## SYSTEM AND METHOD FOR HUMAN MOTION DETECTION AND TRACKING

### PRIORITY STATEMENT & CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 17/362,299, entitled “System and Method for Human Motion Detection and Tracking”, filed on Jun. 29, 2021 in the names of Nathanael Lloyd Gingrich et al., now U.S. Pat. No. 11,331,006, issued on May 17, 2022; which claims priority from co-pending U.S. Patent Application No. 63/155,653, entitled “System and Method for Human Motion Detection and Tracking” and filed on Mar. 2, 2021, in the names of Nathanael Lloyd Gingrich et al.; which is hereby incorporated by reference, in entirety, for all purposes. This application is also a continuation-in-part of U.S. patent application Ser. No. 17/260,477, entitled “System and Method for Human Motion Detection and Tracking”, filed on Jan. 14, 2021, in the name of Longbo Kong, now U.S. Pat. No. 11,103,748, issued on Aug. 31, 2021; which is a 371 national entry application of PCT/US20/21262 entitled “System and Method for Human Motion Detection and Tracking” and filed on Mar. 5, 2020, in the name of Longbo Kong; which claims priority from U.S. Patent Application No. 62/814,147, entitled “System and Method for Human Motion Detection and Tracking” and filed on Mar. 5, 2019, in the name of Longbo Kong; all of which are hereby incorporated by reference, in entirety, for all purposes.

### TECHNICAL FIELD OF THE INVENTION

[0002] The present disclosure relates, in general, to biomechanical evaluations and assessments, which are commonly referred to as range of motion assessments, and more particularly, to automating a biomechanical evaluation process, including a range of motion assessment, and providing recommended exercises to improve physiological inefficiencies of a user.

### BACKGROUND OF THE INVENTION

[0003] Human beings have regularly undergone physical examinations by professionals to assess and diagnose their health issues. Healthcare history has been predominantly reactive to an adverse disease, injury, condition or symptom. Increasingly, in modern times, with more access to information, a preventative approach to healthcare has been gaining greater acceptance. Musculoskeletal health overwhelmingly represents the largest health care cost. Generally speaking, a musculoskeletal system of a person may include a system of muscles, tendons and ligaments, bones and joints, and associated tissues that move the body and help maintain the physical structure and form. Health of a person’s musculoskeletal system may be defined as the absence of disease or illness within all of the parts of this system. When pain arises in the muscles, bones, or other tissues, it may be a result of either a sudden incident (e.g., acute pain) or an ongoing condition (e.g., chronic pain). A healthy musculoskeletal system of a person is crucial to health in other body systems, and for overall happiness and quality of life. Musculoskeletal analysis, or the ability to move within certain ranges (e.g., joint movement) freely and with no pain, is therefore receiving greater attention. However, musculoskeletal analysis has historically been a sub-

jective science, open to interpretation of the healthcare professional or the person seeking care.

[0004] In 1995, after years of research, two movement specialists, Gray Cook and Lee Burton, attempted to improve communication and develop a tool to improve objectivity and increase collaboration efforts in the evaluation of musculoskeletal health. Their system, the Functional Movement Screen (FMS), is a series of seven (7) different movement types, measured and graded on a scale of 0-3. While their approach did find some success in bringing about a more unified approach to movement assessments, the subjectivity, time restraint and reliance on a trained and accredited professional to perform the evaluation limited its adoption. Accordingly, there is a need for improved systems and methods for measuring and analyzing physiological deficiency of a person and providing corrective recommended exercises while minimizing the subjectivity during a musculoskeletal analysis.

### SUMMARY OF THE INVENTION

[0005] It would be advantageous to achieve systems and methods that would improve upon existing limitations in functionality with respect to measuring and analyzing physiological deficiency of a person. It would also be desirable to enable a computer-based electronics and software solution that would provide enhanced goniometry serving as a basis for furnishing corrective recommended exercises while minimizing the subjectivity during a musculoskeletal analysis. To better address one or more of these concerns, a system and method for human motion detection and tracking are disclosed. In one embodiment, a smart device having an optical sensing instrument monitors a stage. A memory is accessible to a processor and communicatively coupled to the optical sensing instrument. The system captures an image frame from the optical sensing instrument. The image frame is then converted into a designated image frame format, which is provided to a pose estimator. A two-dimensional dataset is received from the pose estimator. The system then converts, using inverse kinematics, the two-dimensional dataset into a three-dimensional dataset, which includes time-independent static joint positions, and then calculates, using the three-dimensional dataset, the position of each of the respective plurality of body parts in the image frame. These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0006] For a more complete understanding of the features and advantages of the present invention, reference is now made to the detailed description of the invention along with the accompanying figures in which corresponding numerals in the different figures refer to corresponding parts and in which:

[0007] FIG. 1A is a schematic diagram depicting one embodiment of a system and method for human motion detection tracking for use, for example, with an integrated goniometry system for measuring and analyzing physiological deficiency of a person, such as a user, and providing corrective recommended exercises according to an exemplary aspect of the teachings presented herein;

[0008] FIG. 1B is a schematic diagram depicting one embodiment of the system illustrated in FIG. 1A, wherein a user from a crowd has approached the system;

[0009] FIG. 2 is an illustration of a human skeleton;

[0010] FIG. 3 is an illustration of one embodiment of body parts identified by the system;

[0011] FIG. 4 is a diagram depicting one embodiment of a set number of repetitions which are monitored and captured by the system;

[0012] FIG. 5 is a diagram depicting one embodiment of an image frame processing by the system;

[0013] FIG. 6 is a functional block diagram depicting one embodiment of a smart device, which forms a component of the system presented in FIGS. 1A and 1B;

[0014] FIG. 7 is a conceptual module diagram depicting a software architecture of an integrated goniometry application of some embodiments;

[0015] FIG. 8 is a flow chart depicting one embodiment of a method for integrated goniometric analysis according to exemplary aspects of the teachings presented herein;

[0016] FIG. 9 is a flow chart depicting one embodiment of a method for human motion detection and tracking according to the teachings presented herein; and

[0017] FIG. 10 is a flow chart depicting another embodiment of a method for human motion detection and tracking.

#### DETAILED DESCRIPTION OF THE INVENTION

[0018] While the making and using of various embodiments of the present invention are discussed in detail below, it should be appreciated that the present invention provides many applicable inventive concepts, which can be embodied in a wide variety of specific contexts. The specific embodiments discussed herein are merely illustrative of specific ways to make and use the invention, and do not delimit the scope of the present invention.

[0019] Referring initially to FIG. 1A, therein is depicted one embodiment of a system for human motion detection and tracking that may be incorporated into an integrated goniometry system, for example, for performing automated biomechanical movement assessments, which is schematically illustrated and designated 10. As shown, the integrated goniometry system 10 includes a smart device 12, which may function as an integrated goniometer, having a housing 14 securing an optical sensing instrument 16 and a display 18. The display 18 includes an interactive portal 20 which provides prompts, such as an invitation prompt 22, which may greet a crowd of potential users  $U_1$ ,  $U_2$ , and  $U_3$  and invite a user to enter a stage 24, which may include markers 26 for foot placement of the user standing at the markers 26 to utilize the integrated goniometry system 10. The stage 24 may be a virtual volumetric area 28, such as a rectangular or cubic area, that is compatible with human exercise positions and movement. The display 18 faces the stage 24 and the optical sensing instrument 16 monitors the stage 24. A webcam may be included in some embodiments. It should be appreciated that the location of the optical sensing instrument 16 and the webcam 17 may vary with the housing 14. Moreover, the number of optical sensing instruments used may vary also. Multiple optical sensing instruments or an array thereof may be employed. It should be appreciated that the design and presentation of the smart device 12 may vary depending on application. By way of example, the smart device 12 and the housing 14 may be a device selected from

the group consisting of, with or without tripods, smart phones, smart watches, smart wearables, and tablet computers, for example.

[0020] Referring now to FIG. 1B, the user, user  $U_2$ , has entered the stage 24 and the interactive portal 20 includes an exercise movement prompt 30 providing instructions for the user  $U_2$  on the stage 24 to execute a set number of repetitions of an exercise movement, such as a squat or a bodyweight overhead squat, for example. In some implementations, the interactions with the user  $U_2$  are contactless and wearables. A series of prompts on the interactive portal 20 instruct the user  $U_2$  while the optical sensing instrument 16 senses body point data of the user  $U_2$  during each exercise movement. Based on the sensed body point data, a mobility score, an activation score, a posture score, a symmetry score, or any combination thereof, for example, may be calculated. A composite score may also be calculated. One or more of the calculated scores may provide the basis for the integrated goniometry system 10 determining an exercise recommendation. As mentioned, a series of prompts on the interactive portal instruct the user  $U_2$  through repetitions of exercise movements while the optical sensing instrument 16 senses body point data of the user  $U_2$ . It should be appreciated that the smart device 12 may be supported by a server that provides various storage and support functionality to the smart device 12. Further, the integrated goniometry system 10 may be deployed such that the server is remotely located in a cloud C to service multiple sites with each site having a smart device.

[0021] Referring now to FIG. 2 and FIG. 3, respective embodiments of a human skeleton 60 and body parts identified by the integrated goniometry system 10 are depicted. Body part data 70 approximates certain locations and movements of the human body, represented by the human skeleton 60. More specifically, the body part data 70 is captured by the optical sensing instrument 16 and may include designated body part data 72 and synthetic body part data 74. By way of example and not by way of limitation, designated body part data 72 may include head data 82, neck data 84, right shoulder data 86, left shoulder data 88, right upper arm data 90, left upper arm data 92, right elbow data 94, left elbow data 96, right lower arm data 99, left lower arm data 101, right wrist data 98, left wrist data 100, right hand data 102, left hand data 104, right upper torso data 106, left upper torso data 108, right lower torso data 110, left lower torso data 112, upper right leg data 114, upper left leg data 116, right knee data 118, left knee data 120, right lower leg data 122, left lower leg data 124, right ankle data 126, left ankle data 128, right foot data 130, and left foot data 132. By way of example and not by way of limitation, synthetic body part data 74 may include right hip 140, left hip 142, waist 144, top of spine 146, and middle of spine 148. As will be appreciated, the synthetic body part data 74 may include data captured by the optical sensing instrument 16 that includes locations in the body in the rear of the person or data acquired through inference.

[0022] Referring now to FIG. 4, image frames associated with a set number of repetitions of an exercise movement by the user  $U_2$  are monitored and captured by the integrated goniometry system 10. As shown, in the illustrated embodiment, the user  $U_2$  executes three squats and specifically three bodyweight overhead squats at  $t_3$ ,  $t_5$ , and  $t_7$ . It should be understood, however, that a different number of repetitions may be utilized and is within the teachings presented herein.

That is, N iterations of movement is provided for by the teachings presented herein. At times  $t_1$  and  $t_9$ , the user  $U_2$  is at a neutral position, which may be detected by sensing the body point data within the virtual volumetric area **28** of the stage **24** or at  $t_9$ , an exercise end position which is sensed with the torso in an upright position superposed above the left leg and the right leg with the left arm and right arm laterally offset to the torso.

**[0023]** At times  $t_2$ ,  $t_4$ ,  $t_6$ , and  $t_8$ , the user  $U_2$  is at an exercise start position. The exercise start position may be detected by the torso in an upright position superposed above the left leg and the right leg with the left arm and the right arm superposed above the torso. From an exercise start position, the user  $U_2$  begins a squat with an exercise trigger. During the squat or other exercise movement, image frames are collected. The exercise trigger may be displacement of the user from the exercise start position by sensing displacement of the body. Each repetition of the exercise movement, such as a squat, may be detected by sensing the body returning to its position corresponding to the exercise start position. By way of example, the spine midpoint may be monitored to determine or mark the completion of exercise movement repetitions.

**[0024]** Referring to FIG. 5, by way of example, an image frame **150** is captured having data at a time  $t_1$ . The image frame **150** includes at each image element, coordinate values that are monoptic and represent two-dimensional coordinate values. Pre-processing occurs to the image frame **150** to provide a designated image frame format **152**, which represents the pre-processing of the image frame **150**. Such pre-processing includes isolation of an object, i.e., the user  $U_2$ . Next, as shown at a pose estimator **154**, probability distribution models **156** generated by a neural network **158** are applied to the designated image frame format **152** to identify body parts, such as skeleton points, as shown by two-dimensional dataset **160**.

**[0025]** The two-dimensional dataset **160** is then converted via an application of inverse kinematics **162** into a three-dimensional dataset **164** prior to the position of each of the respective body parts being determined within the three-dimensional dataset **164**. More particularly, as shown, the two-dimensional dataset **160** includes various of the designated body part data **72**, including the head data **82**, the neck data **84**, the right shoulder data **86**, the left shoulder data **88**, the right elbow data **94**, the left elbow data **96**, the right wrist data **98**, the left wrist data **100**, the right knee data **118**, the left knee data **120**, the right ankle data **126**, the left ankle data **128**, the right hip data **140**, and the left hip data **142**, for example. A horizontal axis (designated  $y$ ) and a vertical axis (designated  $x$ ) are defined in the two-dimensional dataset **160**. An intersection is fixed at F between the two-dimensional dataset **160** and the horizontal axis (designated  $y$ ) as a start of a kinematic chain **166**. The intersection corresponds to feet of the user  $U_2$ .

**[0026]** Then, the smart device **12** calculates variable joint parameters under assumptions  $A_1, A_2, A_3$ , for example, that limb lengths  $L_{L1}, L_{L2}, L_{L3}, L_{L4}, L_{L5}, L_{L6}, L_{R1}, L_{R2}, L_{R3}, L_{R4}, L_{R5}, L_{R6}$ , have at least two hinge joints with a component of movement in a depth axis (designated  $z$ ) perpendicular to the horizontal axis (designated  $y$ ) and the vertical axis (designated  $x$ ). In particular, the assumption  $A_1$  relates to the knees, as represented by the right knee data **118** and the left knee data **120**, having a component of movement in a depth axis (designated  $z$ ); the assumption  $A_2$  relates to the hips, as

represented by the right hip data **140** and the left hip data **142**, having a component of movement in a depth axis (designated  $z$ ); and the assumption  $A_3$  relates to the elbows, as represented by the right elbow data **94** and the left elbow data **96**, having a component of movement in a depth axis (designated  $z$ ).

**[0027]** The limb length  $L_{L1}$  defines the length from the left ankle data **128** to the left knee data **120**; the limb length  $L_{L2}$  defines the length from the left knee data **120** to the left hip data **142**; the limb length  $L_{L3}$  defines the length from the left hip data **142** to the left shoulder data **88**; the limb length  $L_{L4}$  defines the length from the left shoulder data **88** to the neck data **84**; the limb length  $L_{L5}$  defines the length from the left shoulder data **88** to the left elbow data **96**; and the limb length  $L_{L6}$  defines the length from the left elbow data **96** to the left wrist data **100**. Similarly, the limb lengths  $L_{R1}, L_{R2}, L_{R3}, L_{R4}, L_{R5}, L_{R6}$  respectively relate to the segments the right ankle data **126** to the right knee data **118**, the right knee data **118** to the right hip data **140**, the right hip data **140** to the right shoulder data **86**, the right shoulder data **86** to the neck data **84**; the right shoulder data **86** to the right elbow data **94**, and the right elbow data **94** to the right wrist data **98**. The limb length  $L_C$  relates to the length from the neck data **84** to the head data **82**.

**[0028]** The smart device **12** also calculates variable joint parameters with respect to limb lengths of the user  $U_2$  required to place the ends of the kinematic chain **166** in a given position and orientation relative to the start of the kinematic chain **166** at the fixed intersection F. The position of each of the body parts in the image frame **150**, which were in two dimensions (e.g.,  $x_n, y_n$ ) is calculated with respect to the image frame **150** to provide three-dimensional coordinates (e.g.  $x_n, y_n, z_n$ ) and provide joint positions, for example, such as angle  $\alpha_n$ .

**[0029]** Referring to FIG. 6, within the housing **14** of the smart device **12**, a processor **180**, memory **182**, and storage **184** are interconnected by a busing architecture **186** within a mounting architecture that also interconnects a network interface **188**, a camera **190**, including an image camera input **192** and/or image camera **194**, inputs **196**, outputs **198**, and the display **18**. The processor **180** may process instructions for execution within the smart device **12** as a computing device, including instructions stored in the memory **182** or in storage **184**. The memory **182** stores information within the computing device. In one implementation, the memory **182** is a volatile memory unit or units. In another implementation, the memory **182** is a non-volatile memory unit or units. The storage **184** provides capacity that is capable of providing mass storage for the smart device **12**. The network interface **188** may provide a point of interconnection, either wired or wireless, between the smart device **12** and a private or public network, such as the Internet. The various inputs **196** and outputs **198** provide connections to and from the computing device, wherein the inputs **196** are the signals or data received by the smart device **12**, and the outputs **198** are the signals or data sent from the smart device **12**. The display **18** may be an electronic device for the visual presentation of data and may, as shown in FIG. 6, be an input/output display providing touchscreen control. The camera **190** may be enabled by an image camera input **192** that may provide an input to the optical sensing instrument **16**, which may be a camera, a point-cloud camera, a laser-scanning camera, an infrared sensor, an RGB camera, or a depth camera, for example, or the camera **190** may be an

image camera **194** directly integrated into the smart device **12**. By way of further example, the optical sensing instrument **16** may utilize technology such as time of flight, structured light, or stereo technology. By way of still further example, in instances where the optical sensing instrument **16** is a depth camera, an RGB camera, a color camera, a structured light camera, a time of flight camera, a passive stereo camera, or a combination thereof may be employed. Further, it should be appreciated that the optical sensing instrument **16** may include two or more optical sensing instruments; that is, more than one sensing instrument may be employed. As mentioned, the smart device **12** and the housing **14** may be a device selected from the group consisting of (with or without tripods) smart phones, smart watches, smart wearables, and tablet computers, for example.

**[0030]** The memory **182** and storage **184** are accessible to the processor **180** and include processor-executable instructions that, when executed, cause the processor **180** to execute a series of operations. In a first series of operations, the processor-executable instructions cause the processor **180** to display an invitation prompt on the interactive portal. The invitation prompt provides an invitation to the user to enter the stage prior to the processor-executable instructions causing the processor **180** to detect the user on the stage by sensing body point data within the virtual volumetric area **28**. By way of example and not by way of limitation, the body point data may include first torso point data, second torso point data, first left arm point data, second left arm point data, first right arm point data, second right arm point data, first left leg point data, second left leg point data, first right leg point data, and second right leg point data, for example.

**[0031]** The processor-executable instructions cause the processor **180** to display the exercise movement prompt **30** on the interactive portal **20**. The exercise movement prompt **30** provides instructions for the user to execute an exercise movement for a set number of repetitions with each repetition being complete when the user returns to an exercise start position. The processor **180** is caused by the processor-executable instructions to detect an exercise trigger. The exercise trigger may be displacement of the user from the exercise start position by sensing displacement of the related body point data. The processor-executable instructions also cause the processor **180** to display an exercise end prompt on the interactive portal **20**. The exercise end prompt provides instructions for the user to stand in an exercise end position. Thereafter, the processor **180** is caused to detect the user standing in the exercise end position.

**[0032]** The processor-executable instructions cause the processor **180** to calculate one or more of several scores including calculating a mobility score by assessing angles using the body point data, calculating an activation score by assessing position within the body point data, calculating a posture score by assessing vertical differentials within the body point data, and calculating a symmetry score by assessing imbalances within the body point data. The processor-executable instructions may also cause the processor **180** to calculate a composite score based on one or more of the mobility score, the activation score, the posture score, or the symmetry score. The processor-executable instructions may also cause the processor **180** to determine an exercise recommendation based on one or more of the composite

score, the mobility score, the activation score, the posture score, or the symmetry score.

**[0033]** In a second series of operations, the processor-executable instructions cause the processor **180** to capture an image frame from the optical sensing instrument **16**. The image frame may include at each image element, two-dimensional coordinate values including a point related to a distance from the optical sensing instrument **16**. Then the processor **180** may be caused to convert the image frame into a designated image frame format. The designated image frame format may include at each image element, coordinate values relative to the image frame. The processor-executable instructions may cause the processor **180** to access, through a pose estimator, and apply multiple probability distribution models to the designated image frame format to identify a respective plurality of body parts. In acquiring the multiple probability distribution models, the probability distribution models may be generated by a neural network. Next, the processor **180** may be caused to calculate the position of each of the plurality of body parts in the designated image frame format and then calculate the position of each of the plurality of body parts in the image frame.

**[0034]** In a third series of operations, the processor-executable instructions cause the processor **180** to capture, via the optical sensing instrument, an image frame relative to a user in a line-of-sight with the optical sensing instrument. The image frame may include at each image element monoptic coordinate values. The processor **180** is then caused by the processor-executable instructions to convert the image frame into a designated image frame format prior to providing the designated image frame format to a pose estimator. The processor **180** is caused to receive a two-dimensional dataset from the pose estimator and convert, using inverse kinematics, the two-dimensional dataset into a three-dimensional dataset. The processor **180** then calculates, using the three-dimensional dataset, the position of each of the respective plurality of body parts in the image frame.

**[0035]** In a fourth series of operations, the processor-executable instructions cause the processor **180** to convert, using inverse kinematics, the two-dimensional dataset into a three-dimensional dataset by first defining a horizontal axis and a vertical axis in the two-dimensional dataset. The processor-executable instructions then cause the processor **180** to fix an intersection of the two-dimensional dataset and the horizontal axis as a start of a kinematic chain. The intersection may correspond to feet of the user. The processor **180** is then caused to calculate variable joint parameters under assumptions that the limb lengths have at least two hinge joints with a component of movement perpendicular to the horizontal axis and the vertical axis. Then the processor **180** calculates the variable joint parameters with respect to limb lengths of the user required to place ends of the kinematic chain in a given position and orientation relative to the start of the kinematic chain.

**[0036]** The processor-executable instructions presented hereinabove include, for example, instructions and data which cause a general purpose computer, special purpose computer, or special purpose processing device to perform a certain function or group of functions. Processor-executable instructions also include program modules that are executed by computers in stand-alone or network environments. Generally, program modules include routines, programs, components, data structures, objects, and the functions inherent

in the design of special-purpose processors, or the like, that perform particular tasks or implement particular abstract data types. Processor-executable instructions, associated data structures, and program modules represent examples of the program code means for executing steps of the systems and methods disclosed herein. The particular sequence of such executable instructions or associated data structures represents examples of corresponding acts for implementing the functions described in such steps and variations in the combinations of processor-executable instructions and sequencing are within the teachings presented herein.

**[0037]** With respect to FIG. 6, in some embodiments, the system for human motion detection and tracking may be at least partially embodied as a programming interface configured to communicate with a smart device. Further, in some embodiments, the processor 180 and the memory 182 of the smart device 12 and a processor and memory of a server may cooperate to execute processor-executable instructions in a distributed manner. By way of example, in these embodiments, the server may be a local server co-located with the smart device 12, or the server may be located remotely to the smart device 12, or the server may be a cloud-based server.

**[0038]** FIG. 7 conceptually illustrates a software architecture of some embodiments of an integrated goniometry application 250 that may automate the biomechanical evaluation process and provide recommended exercises to improve physiological inefficiencies of a user. Such a software architecture may be embodied on an application installable on a smart device, for example. That is, in some embodiments, the integrated goniometry application 250 is a stand-alone application or is integrated into another application, while in other embodiments the application might be implemented within an operating system 300. In some embodiments, the integrated goniometry application 250 is provided on the smart device 12. Furthermore, in some other embodiments, the integrated goniometry application 250 is provided as part of a server-based solution or a cloud-based solution. In some such embodiments, the integrated goniometry application 250 is provided via a thin client. In particular, the integrated goniometry application 250 runs on a server while a user interacts with the application via a separate machine remote from the server. In other such embodiments, integrated goniometry application 250 is provided via a thick client. That is, the integrated goniometry application 250 is distributed from the server to the client machine and runs on the client machine.

**[0039]** The integrated goniometry application 250 includes a user interface (UI) interaction and generation module 252, management (user) interface tools 254, data acquisition modules 256, image frame processing modules 258, image frame pre-processing modules 260, a pose estimator interface 261, mobility modules 262, inverse kinematics modules 263, stability modules 264, posture modules 266, recommendation modules 268, and an authentication application 270. The integrated goniometry application 250 has access to activity logs 280, measurement and source repositories 284, exercise libraries 286, and presentation instructions 290, which presents instructions for the operation of the integrated goniometry application 250 and particularly, for example, the aforementioned interactive portal 20 on the display 18. In some embodiments, storages 280, 284, 286, and 290 are all stored in one physical storage. In other embodiments, the storages 280, 284, 286, and 290 are

in separate physical storages, or one of the storages is in one physical storage while the other is in a different physical storage.

**[0040]** The UI interaction and generation module 250 generates a user interface that allows, through the use of prompts, the user to quickly and efficiently perform a set of exercise movements to be monitored, with the body point data collected from the monitoring furnishing an automated biomechanical movement assessment scoring and related recommended exercises to mitigate inefficiencies. Prior to the generation of automated biomechanical movement assessment scoring and related recommended exercises, the data acquisition modules 256 may be executed to obtain instances of the body point data via the optical sensing instrument 16, which is then processed with the assistance of the image frame processing modules 258 and the image frame pre-processing modules 260. The pose estimator interface 261 is utilized to provide, in one embodiment, image frame pre-processing files created by the image pre-processing modules 260 to a pose estimator to derive skeleton points and other body point data. Following the collection of the body point data, the inverse kinematics modules 263 derives three-dimensional data including joint position data. Then, the mobility modules 262, stability modules 264, and the posture modules 266 are utilized to determine a mobility score, an activation score, and a posture score, for example. More specifically, in one embodiment, the mobility modules 262 measure a user's ability to freely move a joint without resistance. The stability modules 264 provide an indication of whether a joint or muscle group may be stable or unstable. The posture modules 266 may provide an indication of physiological stresses presented during a natural standing position. Following the assessments and calculations by the mobility modules 262, stability modules 264, and the posture modules 266, the recommendation modules 268 may provide a composite score based on the mobility score, the activation score, and the posture score as well as exercise recommendations for the user. The authentication application 270 enables a user to maintain an account, including an activity log and data, with interactions therewith.

**[0041]** In the illustrated embodiment, FIG. 7 also includes the operating system 300 that includes input device drivers 302 and a display module 304. In some embodiments, as illustrated, the input device drivers 302 and display module 304 are part of the operating system 300 even when the integrated goniometry application 250 is an application separate from the operating system 300. The input device drivers 302 may include drivers for translating signals from a keyboard, a touch screen, or an optical sensing instrument, for example. A user interacts with one or more of these input devices, which send signals to their corresponding device driver. The device driver then translates the signals into user input data that is provided to the UI interaction and generation module 252.

**[0042]** FIG. 8 depicts one embodiment of a method for integrated goniometric analysis. At block 320, the methodology begins with the smart device positioned facing the stage. At block 322, multiple bodies are simultaneously detected by the smart device in and around the stage. As the multiple bodies are detected, a prompt displayed on the interactive portal of the smart device invites one of the individuals to the area of the stage in front of the smart device. At block 326, one of the multiple bodies is isolated

by the smart device **12** and identified as an object of interest once it separates from the group of multiple bodies and enters the stage in front of the smart device **12**. The identified body, a user, is tracked as a body of interest by the smart device.

**[0043]** At block **328**, the user is prompted to position himself into the appropriate start position which will enable the collection of a baseline measurement and key movement measurements during exercise. At this point in the methodology, the user is prompted by the smart device to perform the exercise start position and begin a set repetitions of an exercise movement. The smart device collects body point data to record joint angles and positions. At block **330**, the smart device detects an exercise or movement trigger which is indicative of phase movement discrimination being performed in a manner that is independent of the body height, width, size or shape of the user.

**[0044]** At block **332**, the user is prompted by the smart device to repeat the exercise movement as repeated measurements provide more accurate and representative measurements. A repetition is complete when the body of the user returns to the exercise start position. The user is provided a prompt to indicate when the user has completed sufficient repetitions of the exercise movement. With each repetition, once in motion, monitoring of body movement will be interpreted to determine a maximum, minimum, and moving average for the direction of movement, range of motion, depth of movement, speed of movement, rate of change of movement, and change in the direction of movement, for example. At block **334**, the repetitions of the exercise movement are complete. Continuing to decision block **335**, if the session is complete, then methodology advances to block **336**. If the session is not complete, then the methodology returns to the block **322**. At block **336**, once the required number of repetitions of the exercise movement are complete, the user is prompted to perform an exercise end position, which is a neutral pose. Ending at block **338**, with the exercise movements complete, the integrated goniometry methodology begins calculating results and providing the results and any exercise recommendations to the user.

**[0045]** FIG. **9** and FIG. **10** show the methodology in more detail with elements **350** through **366** and elements **380** through **410**. Referring now to FIG. **9**, the methodology begins with block **350** and continues to block **352** where an image frame is captured. The image frame may be captured by the optical sensing instrument. By way of example and not by way of limitation, image frame acquisition may involve obtaining raw image frame data from the camera. Additionally, in some embodiments, the image frame is captured of a user at a known location performing a known movement, such as a squat. At block **354**, pre-processing of the image frame occurs. As previously discussed, during pre-processing, the image frame is converted into a designated image frame format such that at each image element monoptic coordinate values are present relative to the image frame. Also, during the pre-processing, the object—the body of the user—may be isolated. At block **356**, the image frame is converted into the designated image frame format before the submission at block **358** to a pose estimator for the application of a probability distribution model or models occurs for the body parts. Following the return of the data from the pose estimator, at block **360**, inverse kinematics are

applied to infer three-dimensional data, such as joint positions, from the two-dimensional data.

**[0046]** The three-dimensional dataset may include time-independent static joint positions. It is very common for applications using body pose estimation to be focused on time domain measurements, like attempting to gauge the speed or direction of a movement by comparing joint or limb positions across multiple video frames. Often the goal is to classify the observed movement, for instance using velocity or acceleration data to differentiate falling down from sitting down. In contrast, in some embodiments, the systems and methods presented herein focus on accumulating a dataset of static joint positions that can be used to accurately calculate relevant angles between body parts to assess a session of multiple overhead squats. In these embodiments, the systems and methods know in advance exactly where the user is located in the frame and what the movement will be. It is not necessary to use time domain data to identify the movement being performed or to estimate the speed at which it is performed.

**[0047]** In these embodiments, the assessment does not utilize any time domain data to analyze and score performance of the overhead squats. The only reason for use of the time domain data (i.e., across multiple video frames) may be to examine joint position changes in the time domain to determine when a user is no longer moving to inform a prompt to provide next step guidance. While the created dataset contains joint position data for a group of sequential video frames, the analysis of that data is strictly time-independent. The analysis of the joint position frame data for a squat would be the same no matter if the frames were analyzed in the order they were captured or in random order, since angles or scores are not calculated in the time domain. That is, the systems and methods presented herein calculate, using the three-dimensional dataset in a non-time domain manner, a position of each of a respective plurality of body parts in the image frame. The position of each of the body parts may be calculated more accurately at block **364** before the position of each body part is mapped at block **366** and the process concludes at block **368**.

**[0048]** Referring now to FIG. **10**, the methodology is initiated with the operation of the camera at block **380** to ensure the camera is level. At block **382**, the camera captures an image frame, and the methodology detects a body at decision block **384**. If a body is not detected, then the methodology returns to block **382**. On the other hand, if a body is detected, then the position of the body is evaluated at decision block **386**. If the position of the body has issues, such as the body not being completely in the frame or the body not being square with respect to the frame, then the methodology proceeds to block **388**, where a correction is presented to assist the user with correcting the error before re-evaluation at decision block **386**.

**[0049]** Once the position at decision block **386** is approved, then the methodology advances to posture guidance at block **390** before the posture is evaluated at decision block **392**. If the posture of the user is correct, then the methodology advances to decision block **394**. On the other hand if the user's pose does not present the correct posture, then the methodology returns to block **390** where posture guidance is provided. At decision block **394**, if the pose is held long enough then the methodology advances to block **396** where limb length data is saved. If the pose is not held long enough, then the process returns to decision block **392**.

[0050] At block 398, session guidance starts and the session, which presents exercises or poses for the user to complete, continues until completion unless, as shown at decision block 400, the session is interrupted or otherwise not completed. If the session is not completed, as shown by decision block 400, the methodology returns to decision block 384. At block 402 and block 404, the image frame is converted into the processed image frame and recorded two-dimensional skeleton points and limb lengths are utilized with inverse kinematics to calculate relevant angles between body parts. At block 406, the scoring algorithm is applied before scores are presented at block 408. At decision block 410, the scores will be continued to be displayed until the user navigates back to the main screen which returns the methodology to block 382.

[0051] The order of execution or performance of the methods and data flows illustrated and described herein is not essential, unless otherwise specified. That is, elements of the methods and data flows may be performed in any order, unless otherwise specified, and that the methods may include more or less elements than those disclosed herein. For example, it is contemplated that executing or performing a particular element before, contemporaneously with, or after another element are all possible sequences of execution.

[0052] While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments as well as other embodiments of the invention, will be apparent to persons skilled in the art upon reference to the description. It is, therefore, intended that the appended claims encompass any such modifications or embodiments.

What is claimed is:

1. A system for human motion detection and tracking, the system comprising:

a programming interface configured to communicate with a smart device, the smart device including a housing securing an optical sensing instrument, a processor, non-transitory memory, and storage therein, the smart device including a busing architecture communicatively interconnecting the optical sensing instrument, the processor, the non-transitory memory, and the storage; and

the non-transitory memory accessible to the processor, the non-transitory memory including processor-executable instructions that, when executed by the processor, cause the system to:

capture, via the optical sensing instrument, an image frame relative to a user in a line-of-sight with the optical sensing instrument, the image frame including at each image element monoptic coordinate values,

convert the image frame into a designated image frame format,

derive a two-dimensional dataset from the designated image frame format,

convert, using inverse kinematics, the two-dimensional dataset into a three-dimensional dataset, the three-dimensional dataset including a time-independent plurality of static joint positions, and

calculate, using the three-dimensional dataset in a non-time domain manner, a position of each of a respective plurality of body parts in the image frame.

2. The system as recited in claim 1, wherein the processor-executable instructions to convert, using inverse kinematics, the two-dimensional dataset into the three-dimensional dataset further comprise processor-executable instructions that, when executed by the processor, cause the system to:

define a horizontal axis and a vertical axis in the two-dimensional dataset,

fix an intersection of the two-dimensional dataset and the horizontal axis as a start of a kinematic chain, and calculate variable joint parameters required to place ends of the kinematic chain in a given position and orientation relative to the start of the kinematic chain.

3. The system as recited in claim 1, wherein the processor-executable instructions to convert, using inverse kinematics, the two-dimensional dataset into the three-dimensional dataset further comprise processor-executable instructions that, when executed by the processor, cause the system to:

define a horizontal axis and a vertical axis in the two-dimensional dataset,

fix an intersection of the two-dimensional dataset and the horizontal axis as a start of a kinematic chain, the intersection corresponding to feet of the user, and calculate variable joint parameters with respect to limb lengths of the user required to place ends of the kinematic chain in a given position and orientation relative to the start of the kinematic chain.

4. The system as recited in claim 1, wherein the processor-executable instructions to convert, using inverse kinematics, the two-dimensional dataset into the three-dimensional dataset further comprise processor-executable instructions that, when executed by the processor, cause the system to:

define a horizontal axis and a vertical axis in the two-dimensional dataset,

fix an intersection of the two-dimensional dataset and the horizontal axis as a start of a kinematic chain, the intersection corresponding to feet of the user,

calculate variable joint parameters under assumptions that limb lengths of the user have at least two hinge joints with a component of movement perpendicular to the horizontal axis and the vertical axis, and

calculate the variable joint parameters with respect to the limb lengths of the user required to place ends of the kinematic chain in a given position and orientation relative to the start of the kinematic chain.

5. The system as recited in claim 4, wherein the at least two hinge joints comprise joints selected from the group consisting of knees, hips, and elbows.

6. The system as recited in claim 1, wherein the processor-executable instructions to derive the two-dimensional dataset further comprise processor-executable instructions that, when executed by the processor, cause the system to access a neural network to derive the two-dimensional dataset.

7. The system as recited in claim 1, wherein the processor-executable instructions to derive the two-dimensional dataset further comprise processor-executable instructions that, when executed by the processor, cause the system to utilize at least one probability distribution model for the designated image frame format to derive the two-dimensional dataset.

8. The system as recited in claim 1, wherein the processor-executable instructions to derive the two-dimensional dataset further comprise processor-executable instructions that, when executed by the processor, cause the system to determine skeleton point data and body point data to derive the two-dimensional dataset.



9. The system as recited in claim 1, wherein the optical sensing instrument further comprises an instrument selected from the group consisting of a camera, a point-cloud camera, a laser-scanning camera, an infrared sensor, and an RGB camera.

10. The system as recited in claim 1, wherein the optical sensing instrument further comprises a technology selected from the group consisting of time of flight, structured light, and stereo technology.

11. The system as recited in claim 1, wherein the optical sensing instrument further comprises a depth camera.

12. The system as recited in claim 11, wherein the depth camera further comprises a camera selected from the group consisting of a structured light camera, a color camera, a time of flight camera, a passive stereo camera, and combinations thereof.

13. The system as recited in claim 1, wherein the optical sensing instrument further comprises a plurality of cameras.

14. The system as recited in claim 1, wherein the housing of the smart device further comprises a display communicatively interconnected with the busing architecture.

15. The system as recited in claim 14, wherein the memory further comprises processor-executable instructions that, when executed, cause the processor to display on an instruction prompt on an interactive portal of the display, the instruction prompt providing instructions for the user.

16. The system as recited in claim 15, wherein the memory further comprises processor-executable instructions that, when executed, cause the processor to:

- detect the user in a baseline position,
- display an exercise prepare prompt on the interactive portal, the exercise prepare prompt providing instructions for the user to stand in an exercise start position,
- detect the user in the exercise start position,
- display an exercise movement prompt on the interactive portal, the exercise movement prompt providing instructions for the user to execute an exercise movement for a set number of repetitions, each repetition being complete when the user returns to the exercise start position, and
- detect an exercise trigger, the exercise trigger being displacement of the user from the exercise start position by sensing displacement.

17. The system as recited in claim 1, wherein the smart device further comprises a device selected from the group consisting of smart phones, smart watches, smart wearables, and tablet computers.

18. The system as recited in claim 1, wherein the monoptic coordinate values further comprise two-dimensional coordinate values.

19. A system for human motion detection and tracking, the system comprising:

- a programming interface configured to communicate with a smart device, the smart device including a housing securing an optical sensing instrument, a processor, non-transitory memory, and storage therein, the smart device including a busing architecture communicatively interconnecting the optical sensing instrument, the processor, the non-transitory memory, and the storage;
- the non-transitory memory accessible to the processor, the non-transitory memory including first processor-executable instructions that, when executed by the processor, cause the system to:

capture, via the optical sensing instrument, an image frame relative to a user in a line-of-sight with the optical sensing instrument, the image frame including at each image element monoptic coordinate values,

convert the image frame into a designated image frame format,

derive a two-dimensional dataset from the designated image frame format,

convert, using inverse kinematics, the two-dimensional dataset into a three-dimensional dataset, the three-dimensional dataset including a time-independent plurality of static joint positions, and

calculate, using the three-dimensional dataset, the position of each of the respective plurality of body parts in the image frame; and

the non-transitory memory accessible to the processor, the non-transitory memory including second processor-executable instructions that, when executed by the processor, cause the system to:

- define a horizontal axis and a vertical axis in the two-dimensional dataset,
- fix an intersection of the two-dimensional dataset and the horizontal axis as a start of a kinematic chain, and
- calculate variable joint parameters required to place ends of the kinematic chain in a given position and orientation relative to the start of the kinematic chain.

20. A system for human motion detection and tracking, the system comprising:

- a programming interface configured to communicate with a smart device, the smart device including a housing securing an optical sensing instrument, a processor, non-transitory memory, and storage therein, the smart device including a busing architecture communicatively interconnecting the optical sensing instrument, the processor, the non-transitory memory, and the storage; and

the non-transitory memory accessible to the processor, the non-transitory memory including first processor-executable instructions that, when executed by the processor, cause the system to:

- capture, via the optical sensing instrument, an image frame relative to a user in a line-of-sight with the optical sensing instrument, the image frame including at each image element monoptic coordinate values, the user being at a known location, the user performing a known movement,

convert the image frame into a designated image frame format,

derive a two-dimensional dataset from the designated image frame format,

convert, using inverse kinematics, the two-dimensional dataset into a three-dimensional dataset, the three-dimensional dataset including a time-independent plurality of static joint positions, and

calculate, using the three-dimensional dataset, the position of each of the respective plurality of body parts in the image frame.

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