

METHOD AND SYSTEM FOR JOINT ANGLE CALIBRATION FOR A WEARABLE SENSING DEVICE

Technical Field

[0001] The present invention generally relates to movement monitoring and calibration for physical therapy, and more particularly relates to methods and systems for joint angle calibration for a wearable sensing device.

Background

[0002] After accidents or orthopaedic surgeries, people who have undergone joint replacement or joint treatment surgeries are usually required to go for a prolonged rehabilitation process after being discharged from hospitals. Such rehabilitation may include physical rehabilitation in which damaged or unused muscles, nerves and/or joints are exercised by physical therapy. A common indicator of the rehabilitation recovery progress used by clinicians is the Range of Motion (ROM) of a joint that is measured using a handheld goniometer, by placing parts of the goniometer at certain clinically defined anatomical landmarks and reading off an anatomical joint angle value directly from the goniometer. Typically, the ROM is taken by an experienced clinician/nurse in a rehabilitation centre and involves the personal attention of a physical therapist that monitors and instructs a user in the performance of certain exercises. ROM measurements are also used in mobility-related rehabilitation undergone by stroke, diabetic, and heart disease patients.

[0003] Nowadays, exercises in rehabilitation program can be designed for both home and rehabilitation centres, and many people perform rehabilitation programs in their own homes. Without a physical therapist being physically present, proper compliance and monitoring are inevitably compromised for at-home rehabilitation programs. Consequently, physical therapists are not able to determine the correctness and quality of performed exercises in such situations, or whether the person followed the rehabilitation program at all. They must rely on the office visits to ascertain progress. Further, if exercises are carried out inadequately or wrongly, one may suffer from long lasting side effects later.

[0004] Some clinicians have started using other instruments for measuring ROM for users performing rehabilitation programs at home, without being supervised by experienced clinicians or nurses. These instruments may take the form of a wearable sensing device attached near the vicinity of the joint to be measured. In order to provide reliable data for clinician and to the user, there is a need to have a high accuracy of the measurements, and the instruments should be

calibrated to the user's anatomical features surrounding the joint. However, current methods of calibration (e.g. two-step calibration using 2 or more known angles, such as 0° and 90°) may be subject to many possible human errors. Additionally, since the age group of users who have undergone such surgeries tend to be high, there may be technological knowledge required for the calibration process which these users do not have.

[0005] Accordingly, what is needed is a method and system for easy and accurate joint angle calibration for a wearable sensing device and use of the system for joint angle measurements that seeks to address one or more of the above-mentioned problems. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the disclosure.

Summary

[0006] According to a first aspect of the present disclosure, there is provided a computer-implemented method for joint angle calibration for a wearable sensing device, the wearable sensing device being attached to two segments of a user's body connected by a joint. The method includes the steps of: receiving a first and a second set of image data, corresponding to images of the two segments of the user's body and the wearable sensing device attached thereto at a first position and a second position, the first and second positions in substantially the same plane; determining a first joint angle between the two segments at the first position based on the first set of image data and a second joint angle between the two segments at the second position based on the second set of image data; receiving raw data from the wearable sensing device, the raw data measured by the wearable sensing device coincidentally with the wearable sensing device being at the first position and being at the second position; generating calibration data to calibrate the wearable sensing device based on the first and the second joint angles and the raw data from the wearable sensing device; and transmitting the calibration data to the wearable sensing device for calibrating the wearable sensing device for subsequent use.

[0007] In some implementations, the method may include steps of computing a third joint angle corresponding to a third position in substantially the same plane with the first and second positions, and sending a warning if the third position is not in substantially the same plane with the first and second positions. In addition, the method may include steps of evaluating the first and second sets of image data to determine if a quality of the image data is acceptable, and/or presenting guidance on obtaining the first and second sets of image data that is acceptable. Preferably, the method may also include presenting a recommended location for attaching the

wearable sensing device to the two segments of the user's body, based on anatomical landmarks identified by a computer vision algorithm.

[0008] According to a further aspect of the present disclosure, there is provided an apparatus for joint angle calibration for the wearable sensing device. The apparatus includes: an image capturing device configured to capture an image or a video; at least one processor in communication with the image capturing device; and at least one memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus to perform the method in the first aspect. The present disclosure further provides a non-transitory computer readable medium having stored thereon instructions executable by a computing device to cause the computing device to perform the method in the first aspect, as well as a system for joint angle calibration that includes the wearable sensing device configured to be attached to two segments of a user's body connected by a joint and the aforesaid apparatus.

Brief Description of Drawings

[0009] Embodiments of the disclosure will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

[0010] Fig. 1A depicts an illustration of a system for joint angle calibration for a wearable sensing device in accordance with the present embodiments.

[0011] Fig. 1B depicts a flowchart illustrating a method for using the system for joint angle calibration in accordance with the present embodiments.

[0012] Figs. 2A-2B depict an exploded view and a cross-sectional view, respectively, of the wearable sensing device and its components in accordance with the present embodiments.

[0013] Fig. 3A depicts an illustration of bending planes of the wearable sensing device in accordance with the present embodiments.

[0014] Fig. 3B depicts an illustration of determining a bending angle of the wearable sensing device in accordance with the present embodiments.

[0015] Figs. 4A-4D depict illustrations of the placements of the wearable sensing device on a user's body in accordance with the present embodiments.

[0016] Fig. 5 depicts an illustration of a plurality of camera positions for image capturing in accordance with the present embodiments.

[0017] Figs. 6A-6C depict an illustration of processes of determining a joint angle from the image in accordance with the present embodiments.

[0018] Fig. 6D depicts an illustration of a user error in the placement of the wearable sensing device in accordance with the present embodiments.

[0019] Fig. 7 depicts a flow diagram illustrating a calibration process of the wearable sensing device in accordance with the present embodiments.

[0020] Fig. 8 depicts a block diagram of a computing device suitable for use in the system for joint angle calibration in accordance with the present embodiments.

[0021] Fig. 9 depicts a flowchart illustrating using the system for joint angle calibration at different stages from pre-operation to recovery in accordance with the present embodiments.

[0022] Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been depicted to scale. For example, the dimensions of some of the elements in the illustrations, block diagrams or flowcharts may be exaggerated in respect to other elements to help to improve understanding of the present embodiments.

Detailed Description

[0023] The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any theory presented in the preceding background of the invention or the following detailed description. It is the intent of the present embodiments to present a method, apparatus and system to calibrate joint angles for a wearable sensing device to help physical therapists and other medical professionals monitor the user's rehabilitation programs. The method uses a proprietary algorithm to determine the joint angle between two segments of the body connected at a common joint rotating in approximately the same plane, by means of computer vision technology.

[0024] Fig. 1A illustrates an exemplary system 100 for joint angle calibration for a wearable sensing device 200a, 200b, and 200c. The system 100 includes a computing device 110 which may be any of a variety of computing devices, such as a smartphone 112, a tablet 114, a computer 116, a PDA, or other similar devices or a combination of two or more of such devices, which may

be compatible with software for calibration and have sufficient computing capabilities. The software may include a calibration algorithm as an integrated part run by the computing device 110. The computing device 110 may possess computer vision capabilities and may additionally include an image capturing device or work with a separate image capturing device to function as a single apparatus for joint angle calibration for the wearable sensing device 200a, 200b, and 200c. As shown in Fig. 1A, once the wearable sensing device 200a has synced with the computing device 110, data can be transmitted 122, 124 between them for further calibration and measuring processes.

[0025] The transmission 122, 124 of signals 120 between the wearable sensing device 200a and the computing device 110 may occur throughout the calibration process or the measurement process afterwards, coordinated by the software downloaded into the computing device 110. The transmission 122, 124 may be radio frequency (RF) communications broadcasted and received through Wi-Fi modules, Bluetooth modules or a combination of both, which may be built into the wearable sensing device 200a and the computing device 110. Preferably, the computing device 110 is in proximity to the wearable sensing device 200a, thereby reducing background interference to the RF signals 120.

[0026] Fig. 1B is a flowchart 150 illustrating an exemplary method for using the system 100. At step 152, the wearable sensing device 200a is worn on the user's body, being attached on two segments of the body connected by a joint. Proceeding to step 154, software in the computing device 110 is synced with the wearable sensing device 200a. This allows the wearable sensing device 200a and the software to transmit required data to each other to carry out the calibration step 156. Calibration of the wearable sensing device is paramount because anatomical joint position and/or sizes differ among users. In some situations, the sensing tube 12 (see Fig. 2A) of the wearable sensing device may not be centralised above an anatomical joint, or bodies 10, 14 may not be positioned at the ideal anatomical landmarks due to possible shortage of length of the sensing tube 12, or deformity of the area on or surrounding the anatomical joint. Such situations can result in different conversion formulas (e.g. formulas used to convert the measured capacitance, voltage or other data to a joint angle) for different users. Details of the calibration step will be further discussed, with reference to Fig. 7. After the calibration step 156, the wearable sensing device 200a will be ready for use for joint angle measurements at step 158. In an embodiment, the measurement data of the wearable sensing device 200a can be wirelessly monitored for clinical and/or other purposes.

[0027] Fig. 2A is an exploded view of an exemplary wearable sensing device 200 and its components. The wearable sensing device 200 includes two modules: a larger rigid body 10 and

a smaller rigid body 14, and includes a sensing tube 12 as a flexible member connecting the two modules. In some embodiments, the sensing tube 12 is made of compliant non-conducting layers sandwiched between two compliant conducting layers. The sensing tube 12 connects to a printed circuit board (PCB) 16 located in the larger rigid body 10 on one end, and connects to the smaller rigid body 14 on the other end. The PCB may include a transmitting module and a receiving module for transmitting and receiving data and/or signals. In an embodiment, the PCB may also contain components to store data.

[0028] When in use, the wearable sensor device 200 is to be attached to two anatomical segments of the user's body which are connected by an anatomical joint (e.g. shoulder, neck, knee, hip), with the larger rigid body 10 on a first anatomical segment and the smaller body 14 on a second anatomical segment. In some embodiments, the attachment can be realized by means of magnets 18 and 26, skin clips 22 and 24 and biocompatible adhesives 28, 30 and 32. In an implementation, the adhesives 30, 32 are first adhered on different segments of the user's skin, after which top-side adhesives 28 attach the skin clips 22, 24 to the adhesives 30, 32. Magnets 26 attached to the skin clips 22, 24 and magnets 18 attached to the bodies 10, 14 (as shown in Fig. 2B) have opposite poles, thereby allowing bodies 10, 14 to be attached to the skin clips 22, 24 by means of magnetic attraction. In another implementation, skin clips 22, 24 can first be attached to the bodies 10, 14. Top-side adhesives 28 can subsequently be attached to the skin clips 22, 24. Finally, the bottom-side adhesives 30, 32 can then be placed on the desired location of the user, with the entire wearable sensing device 200. The implementations for attaching the wearable sensor device are not limited.

[0029] The wearable sensing device 200 may be activated by means of a battery 20 embedded in an open circuit, which is closed when a hall-sensor switch is triggered by magnets 26 and 18's attraction to bodies 10 and 14. The battery 20 can power components in the PCB 16, and components in the PCB 16 can detect, to a significant accuracy and precision, the capacitance change due to bending of the sensing tube. Bodies 10, 14 may be made of acrylonitrile butadiene styrene (ABS) plastic casings that are tightly closed to keep a secure connection to the sensing tube, as well as to keep the PCB 16 in place in the larger rigid body 10.

[0030] In further embodiments, components of the wearable sensing device 200, such as the bodies, the sensing tube, the attachment means, and the electronic components may have different sizes, shapes, materials, rigidities and arrangements as long as they are suitable for the aforementioned uses and purposes.

[0031] Fig. 3A illustrates exemplary rotations or bendings of the wearable sensing device 200 and the bending planes. The sensing tube 12 is capable of functioning in 3 planes of rotation 34,

40 and 41. In the example shown, the sensing tube can be bent in the plane 40, moving body 14 between positions P and P'. In some embodiments, a change in the capacitance of the sensing tube 12 relates to, for example, is proportional to the magnitude of bending of the sensing tube 12 from its central axis 38. This capacitance change can be detected along the length of the sensing tube 12 by components in the PCB 16, and then converted to measurements or raw data of the angular displacement of the bodies 10 and 14 relative to orientation between the first and second vectors 36 and 44 defined by the bodies 10 and 14, respectively. While capacitance change is used as an example here, changes in voltage, current, resistance, impedance, or physical changes affected by these electrical signals may also be used as raw data.

[0032] Fig. 3B illustrates an example of an angular displacement of an angle 46. The sensing tube 12 is bent in the plane 34, causing a displacement of the smaller body 14. The angle 46 is formed by vectors 36' and 44, and can be determined by extending the vector lines 36' and 44 (dotted lines 38' and 38, respectively). The magnitude of bending of the sensing tube 12 due to the displacement of the smaller body 14 will generate a corresponding change in capacitance within sensing tube 12. One can appreciate that angular displacements can also be caused by the displacement of the larger body 10 in relation to the smaller body, or both bodies 10, 14 in relation to each other, as long as a relative displacement of the bodies 10, 14 is present.

[0033] Figs. 4A-4D illustrates exemplary placements of the wearable sensor device 200 on a user's body. Referring to Fig. 4A, the wearable sensing device 200 can be placed on lower body limbs, where the centres of the sensing tubes 12 are located approximately on the surface of anatomical landmarks which demark the anatomical joint at that region, such as at the hip joint 46, the knee joint 48, or the ankle joint 50. Accurate placement of the wearable sensing device 200 may be done by locating nearby anatomical landmarks, adopting the techniques used in clinical standards of joint measurement. With reference to the knee joint 48 in the present embodiment, the larger body 10 is placed on a first anatomical segment above the knee joint 48, and the smaller body 14 is placed on a second anatomical segment below the knee joint 48, with the sensing tube 12 lying across the knee joint 48. Bending of the knee, for example in direction 54, via movements of one or both segments causes joint rotation 52 and a displacement of smaller body 14, which in turn results in a bending of the sensing tube 12 where a change in capacitance is detected as previously described.

[0034] Referring to Figs. 4B-4D, the wearable sensing device 200 can also be placed on the elbow joint 60, the neck joint 56, and the shoulder joint 58. One may appreciate that the wearable sensing device 200 is suitable for any joint between the first and second segments and connecting the two segments. In the embodiments where the anatomical joints like 56, 58 and 60 have

several planes of rotation, the wearable sensing device 200 is advantageously capable of capturing these changes of capacitance in different planes of rotation through measuring the proportional capacitive change measured by the bending of the sensing tube 12, as previously described. In some embodiments, an algorithm may be used to guide the user to such exemplary placements of the device without requiring professional clinical knowledge of anatomical landmarks, for example, through a machine learning based computer vision system that is trained to identify anatomical landmarks of joints, such as the hip joint 46, knee joint 48 or ankle joint 50. By training the computer vision system with sufficient amount of sample data, the computer vision system may be able to identify the respective anatomical landmarks for placing the wearable sensing device 200 with high accuracy. Based on the identified anatomical landmarks, the algorithm may be able to generate reference lines, which can assist to determine the "correct" / "recommended" location to place the wearable sensing device 200. By doing so, the user may be able to place the device at the "ideal" location, and corrections can be provided by the algorithm if needed. Once the user sets up the device in the "recommended" location, he/she may proceed to take a photo of the current device placement, then the system can proceed to calibrate the data collected according to the placement of the device 200, which can be done by computer vision techniques for angle detection.

[0035] In an exemplary implementation, after activating a placement mode on the mobile application, the user may be required to input on the mobile application the type of joint to be measured, then to hover the mobile device over the joint with the back camera facing the joint and the display screen of the mobile device facing the user, such that the user will be capable of seeing the contents within the display screen of the mobile device. The mobile application can then show, using cues such as dotted lines, the user the ideal placement of the device deduced by identifying the previously mentioned anatomical landmarks on the joint specified by the user. Other cues, such as a green or red frame along the perimeter of the display screen, can also be used to indicate, in real-time, if the current placement is right or wrong. On confirming that the user has completed placing the device, either through the user's own input of confirmation, or an automatic detection via the computer vision algorithm, the application will take a first image or set of images for the calibration mode following placement.

[0036] Fig. 5 illustrates a plurality of camera positions 62, 74, 76 for image capturing. The images or videos captured by the image capturing device (e.g. a mobile phone 112 or a tablet 114 as shown in Fig. 1A), upon image processing, are used for calibration of the wearable sensing device 200 by relating placement of the wearable sensing device 200 to the anatomical joint.

[0037] In a preferred embodiment, the images (or videos) taken by the image capturing device are taken from a position 74 axially perpendicular to the anatomical joint, with the entirety of the wearable sensing device 200 clearly seen within the viewing screen 68. Preferably, the anatomical joint should be approximately centred in the image or video. Preferably, reasonable lengths of the first and second leg segments are shown within the image. Further, relevant anatomical landmarks may be present in the image or video (e.g. the knee). While the image capturing device should be as near to the wearable sensing device 200 such that there is little or no background interference to the signals, the image capturing device should also be far enough to capture an image that fulfils the above requirements.

[0038] Preferably, after taking a first image, a second image may be taken with the anatomical joint in a different measurable joint angle position with the image capturing device in the same axially perpendicular position 74, and having all elements of image content as the first image. Preferably, all the unimportant contents of the first and second images (e.g. background surrounding the joint and the two segments) are aligned the same way except the main subjects of the image (i.e. the wearable sensing device, anatomical joint, two segments that form the joint). Advantageously, these images may allow the calibration software to determine the joint angles using predicted positions of anatomical landmarks, relate the joint angles to the magnitudes of bending in the sensor tube 12, and subsequently compute a formula that relates the two using raw data (e.g. capacitance measurements) corresponding to the magnitudes of the bending measured by the sensing tube 12 coincidentally with taking the first and second images, the raw data being transmitted by a component in the PCB 16.

[0039] In other embodiments, the position of the image capturing device may be in positions 62, 76 deviating from the direct perpendicular axis of the joint, due to parallax error by the user or other circumstances. A working angle 70 is defined as the allowable amount of angular deviation from the perpendicular axis such that the entirety of the wearable sensing device 200 in the viewing screens 64, 66 should be visible, and that a change in joint angle should produce a visible change in bending of sensing tube 12 in the viewing screens 64, 66 of the image capturing device, regardless of the orientation or position 62, 74 or 76 of the image capturing device. Further, a working resolution (not shown) is defined as the allowable resolution that allows the wearable sensing device 200 and other important contents of the image or video to be detected by the software. The working resolution can be a combinational result of the distance 72 of the image capturing device from the anatomical joint, the technical capabilities of the camera located in the image capturing device, and the method of taking the image or video by the user. Preferably, the image or video should be taken at a sufficient distance from the joint, at an angle approximately perpendicular to the said joint and at a sufficient resolution with sensible clarity (e.g. image should

not be out of focus, contain moving bodies, hard to differentiate between contents and background). Both working angle and working resolution should be in allowable ranges such that the image data is within an acceptable quality range for the calibration to be successfully computed.

[0040] In other embodiments, instead of two separate images, a plurality of images as an image set can be taken to correct errors due to motion during the image capturing process. Preferably, images in the image set may be averaged by an algorithm of the software to obtain a better image quality. Advantageously, the raw data transmitted by the wearable sensing device 200 can be represented better and computing time can be reduced. Also, image set or video inputs can improve robustness of computer vision algorithm when used to generate the calibration formula. Further, image sets can show the motions of the user during the image capturing process, which allows the algorithm of the software to compute the direction and magnitude of motions and correct for blurriness arising from the motion. This also allows a larger margin of user error for the calibration process which is highly beneficial to the user.

[0041] Figs. 6A-6C illustrates processes of determining a joint angle from an image. Referring to Fig. 6A, upon receiving an image (being an image directly captured by the image capturing device such as a tablet 114, or an image averaged from an image set or frames of a video), the algorithm of the software may identify important elements in the image required for the computation, which can include the wearable sensing device 200, the anatomical joint 48, and anatomical landmarks (not shown). Fig 6B shows an example of the elements identified by the algorithm. The elements are represented by having thicker lines as the outlines of body and the wearable sensing device 200, and having square shaped points 84, 86 and 88 as points of interest (i.e. anatomical landmarks and anatomical joint). The algorithm may then predict a midline 80 of the first segment and a midline 82 of the second segment that intersect at the “predicted” anatomical joint 88. For predicting the midlines, it is also possible to have signs or labels on the covers of the large and small bodies of the wearable sensing device, such that the computer vision technique can pick up these signs or labels which can facilitate the midline prediction. Further, by identifying the outline of the sensing tube 12, the algorithm computes the bending of the sensing tube 12 and relates this magnitude of bending to the data transmitted by the wearable sensing device 200, which corresponds to the particular curvature shown in the image. Referring to Fig 6C, the algorithm proceeds to compute the joint angle. In some embodiments, the algorithm takes the first segment midline of 80 that passes through a first predicted position of anatomical landmark 84 and extending it to obtain line 90 as a 0° reference point. Then the algorithm takes the second segment midline 82 that passes through a second predicted position of anatomical

landmark 86 as the displaced line. Using the “predicted” anatomical joint 88 as the pivot point, the algorithm can output the angle 92, which will be the computed joint angle. In a similar manner, the algorithm may compute the bending and joint angle from the second image, and thereafter generate calibration information (e.g. compute a calibration formula) to calibrate the wearable sensing device 200 based on the two images. In some embodiments, determining the joint angle can utilize computer vision techniques.

[0042] Fig. 6D illustrates an exemplary placement of the wearable sensing device 200 occurring as part of a possible user error. Instead of placing the larger body 10 along the lateral midline of the segment 80, the larger body 10 can be placed anteriorly by a distance represented by the arrow 96 to a position 94. Consequently, the sensing tube 12 is displaced to a position that deviates from the anatomical joint. It is beneficial to the user that, in such scenarios, calibration formula may still be computed, for example, by using processes such as Kalman filtering. Using similar steps described in previously embodiments, the algorithm will relate the placement of the wearable sensing device 200 at this position 94 with the computed joint angle 92, and a calibration formula computed can relate the different bending of the sensing tube 12 due to misplacement to correctly determined joint angles 92, which advantageously reduces the impact of user error.

[0043] Fig. 7 is a flow diagram illustrating an exemplary calibration process 156 of the wearable sensing device 200. In some embodiments, the calibration starts 128 by means of a user-activated first virtual button on the software in a compatible image capturing device, after successful syncing of the wearable sensing device 200 with the software.

[0044] To begin, the user may be directed to take a first set of images, for example, by on-screen texts that describe ideal camera placement to guide the user in taking the optimal image as previously described. The user may also be guided by other means of indication, for example, by means of an on-screen border that borders the perimeter of the screen and that can change in colours. In an embodiment, the border can change to green, signifying acceptable image or video quality; and the border can change to red, signifying unacceptable image or video quality. In other embodiments, the user may also be guided by an audio message, a video, or the like.

[0045] The user may, if permitted by the technological capabilities of the image capturing device, choose to switch between front-facing camera and back-facing camera, by pressing a second virtual button located on the screen, depending on the user’s personal preference. The user may take an image by pressing a button of the image capturing device or pressing a third virtual button on the screen. If permitted by the technological capabilities of the image capturing device, the software may capture a plurality of images in a burst shot or a video within a set interval of time.

In other embodiments, an image or a video can be readily available (i.e. without the need for the user to capture one), and can be provided by the user for the calibration process.

[0046] The image or video captured is processed and used as the first set of image data for inputting into the algorithm. In some embodiments, the algorithm may analyse the plurality of images or the frames of the video and averages them into a singular averaged image of highest quality that best represents the instance of capture, and the same is used the first set of image data. At step 130, the first set of image data is received by the processor of the computing device 110.

[0047] In some embodiments, the algorithm may evaluate the first set of image data to check 132 if quality of the image data is acceptable, for example, to check if it fulfils certain requirements as previously discussed (e.g. presence of the entire wearable sensing device, resolution of the image, etc.). The algorithm may check for subject anatomical joint and attempt to identify the type of joint. The algorithm may also check to see if the entire wearable sensing device 200 is captured. Further, the algorithm may also check the motion and the orientation of the image capturing device when the image or video was captured. The algorithm may then check for presence of anatomical landmarks in the first set of image data, or, if there is none or few of them, attempt to predict the location of anatomical landmarks relative to the part of the body that is within view, for example, by using predicted segment midlines 80, 82 as shown in Fig. 6B. In other embodiments, if any check or attempt in predicting fails or a quality of the first image and/or second image is found to not be within a predetermined acceptable quality range, the first set of image data is deemed unacceptable and the algorithm will present a quality message and prompt the user to repeat the process of capturing the first set of images or video with the image capturing device again. The acceptable quality range can be predefined by the user and/or the doctors, clinicians or therapists, pre-set at predetermined default values or determined in response to previous calibrations.

[0048] In evaluating the first set of image data, if all checks and attempts are successful, and the quality of the first set of image data is deemed acceptable. The user is then prompted to take or provide a second set of image data with the user's two segments of the body connected by the anatomical joint at a different position, and the anatomical joint in a different angle. Preferably, the second set of image data is taken from an angle and distance similar to the conditions of the first set of images. At step 134, the second set of image data is received by the processor of the computing device 110. In some embodiments, the second set of image data will be evaluated to determine 136 if its quality is within an acceptable quality range. If any checks and attempts fail, the second set of image data is deemed unacceptable and the algorithm will prompt the user to repeat the process of capturing the second set of images with the image capturing device again.

[0049] When the first set of image data is received (or accepted in those embodiments with a quality evaluation step), the algorithm may determine a first joint angle corresponding to the first set of image data. Determining the joint angle can be done by the process described in Figs. 6A-6C. In some embodiments, the joint angle can be determined by means of computer vision technology. Similar process can be used for the second set of image data to determine a second joint angle corresponding to the second set of image data. One may appreciate that determining the joint angle can be done after each set of image data is received, or as shown in step 138 in FIG. 7, after all sets of image data are received.

[0050] When the second set of image data is received (or accepted in those embodiments with a quality evaluation step), the algorithm may also send a signal to the receiving module of the wearable sensing device 200 via the computing device 110. The software then expects to receive a return signal from the wearable sensing device 200, which contains raw data based on a time interval of the angular states during which the wearable sensing device collected. The time interval can include before, during and after the first set of image data was taken. In the previously described embodiments, the raw data is the capacitance of the sensing tube 12. One may appreciate that in other embodiments, the raw data can also be measurements in voltage, current, resistance, impedance, or physical changes affected by these electrical signals. The raw data may be in the form of binary, decimal, hexadecimal numbers stored in lists, tuples, or other forms of variables of different programming languages. The implementations are not limited. Similar process can happen after receiving the second set of image data, and the wearable sensing device 200 sends a return signal containing raw data based on a time interval of the angular states. In some embodiments, the return signal can be sent by the wearable sensing device 200 after each set of image data is received or after all sets of image data are received.

[0051] In some embodiments, the algorithm checks 140 if a return signal from the wearable sensing device 200 is received and if the raw data contained in the return signal is complete. In some embodiments, failures may include incomplete data where there is no recorded data in a certain period of time, faulty data, where many outliers are present or no data received. In such embodiments, the software checks 142 if repeated failure has occurred previously for up to a predetermined times (e.g. 3 times). If number of failure has not reached 3 times, it may request the device for the required data again without requiring user input. If retry has exceeded 3 times, the algorithm may be able to check for the type of failure and send the user an error message at step 144, with advice on how to troubleshoot the error based on the type of failure. In some embodiments, the error message may advise the user to either check if the device is synced with the mobile platform, or to remove any other device that could interfere with signals either to or from the image capturing device.

[0052] In other embodiments, if complete raw data is successfully received by the computing device 110, the algorithm proceeds to step 146 to generate calibration data for calibrating the wearable sensing device based on the first and second joint angles determined at step 138 and the raw data measured by the wearable sensing device coincidentally with the device being at the first position and being at the second position. Generating the calibration data may include computation of a calibration formula which converts the raw data from the wearable sensing device 200 (e.g. capacitance) to real-time anatomical joint angles. On successful computation, the algorithm may store relevant details such as the calibration conditions, calibration formula and conversion information at step 148. In a preferred embodiment, the relevant details are stored on a cloud database. Alternatively, they may be stored on a memory stick of the image capturing device or, in other embodiments, on the device's memory.

[0053] At the generating calibration data step 146, in some embodiments, the algorithm may analyse the plurality of pixels and normalise pixel colour to identify key parts of user input images that will be used to more precisely and accurately determine calibration formula. In a further embodiment, the algorithm may correct small flaws or errors with user input image sets or videos to reduce the noise and make the comparison between both image sets or videos and the computation of calibration formula less complex. In a further embodiment, the algorithm may compare the plurality of sets of raw data with user image set or video inputs to determine average joint angle movement during image set or video taking. In a further embodiment, the algorithm may identify locations of anatomical landmarks present or absent from the user input image sets or videos and may use these landmarks locations to identify or predict the pivot point of joint in questions. In a further embodiment, the algorithm will display a loading screen while it computes the calibration formula.

[0054] In preferred embodiments, once relevant details have been stored successfully, the algorithm may notify the user with a success message at step 160, either in words or image or both, that the wearable sensing device has been calibrated and the user is ready to use the device. In some embodiments, the success message can be in the form of a green tick on screen. In some embodiments, the success message may be flashed across the visual display of the image capturing device for a set time (e.g. 2-5 seconds), after which the message fades away signifying the end 162 of the calibration process 156.

[0055] After the completion of the calibration process 156, the system 100 is ready to use for joint angle measuring process. The processor of the computing device 110 may receive new raw data (e.g. capacitance of the sensing tube 12) corresponding to the two segments of the user's

body at a third position or subsequent positions, and compute a third joint angle or subsequent joint angles based on the new raw data using the calibration data generated at step 146.

[0056] The flow diagram in Fig. 7 is an exemplary calibrating process when the wearable sensing device moves within one plane. In other embodiments, the algorithm may also check if the third position is in substantially the same plane with the first and second positions. Advantageously, the algorithm can identify if the user's joint in question is rotating in an awkward manner that may be damaging to the user unbeknownst to them. This can be done by analysing the joint rotation in several planes, then identifying which rotations should not be allowed in the current state the user is in. When several planes are involved, preferably, each plane requires a minimum of two images produced in the same manner for calibration. The images should be captured to provide several points of views of the sensing device. Alternatively, if the image capturing device is placed with a view of all 3 planes (e.g. from a corner as in Fig. 3A), and images produced sufficiently capture the required contents (the wearable sensing device, anatomical landmarks, anatomical joint rotation in 3 planes in a single image), then a minimum of two images can sufficiently calibrate all 3 planes. In implementations, if the device (or the sensing tube) is displaced sufficiently in the various planes, the algorithm be able to calculate the real-world displacement in each of these planes and relate that to the capacitance change detected in various planes. A formula can be generated to relate subsequent capacitance change in each plane with the real-world displacement of the wearable sensing device, hence relating to the real-world displacement of the user's joint and segments. When there are multiple images to be captured for calibration in several planes, for a better usability, one or more videos can be taken instead with the image capturing device shifting from one plane to the next, with the movements of the joint rotating in the required planes. In a preferred embodiment, by being able to measure joint angles in several planes, the algorithm may send a warning if the third position is not in substantially the same plane with the first and second positions, or it is in a plane which rotation of the joint should not be allowed.

[0057] Fig. 8 is a block diagram of an exemplary computing device 110 suitable for use in the system 100 for joint angle calibration. In implementations, the computing device 110 can be generally described as one or more physical devices including at least one processor 802 and at least one memory 804 including computer program code. The at least one memory 804 and the computer program code are configured to, with the at least one processor 802, cause the server to implement the calibration step 156 described with reference to FIG. 7. The computing device 110 can include an image capturing device 806, configured to capture images of the user's joint and the wearable sensing device as described with reference to FIG. 5. The computing device 110 may additionally include a display and a speaker for presenting quality messages, feedback

messages, guidance messages or videos. The description of the computing device 110 is provided by way of example only and is not intended to be limiting.

[0058] Fig. 9 is a flowchart 900 illustrating using the system 100 for joint angle calibration at different stages from pre-operation to recovery. The system includes the wearable sensing device 200 and an apparatus having an image capturing device 806, a processor 802 in communication with the image capturing device 806, and at least one memory 804 including computer program code. The system 100 can be used on different types of users under different conditions as described below.

[0059] In some embodiments, patients at a pre-operation stage 902 who are expected to undergo certain joint surgery may use the system 100 to measure 912 the patients' pre-operation joint angles, monitored by the clinicians. In these situations, the patient's joint may be deformed due to various circumstances (e.g. swelling, torn ligaments/muscles). After evaluating pre-operative measurements, clinicians proceed with the operation and start intra-operation stage 904. After the operation, the patient may be expected to undergo a post-operative stage 906 with recovery process or rehabilitation to nurse and retrain muscles surrounding the operated joint. During the rehabilitation process and before the stage of full recovery 908, the system 100 can be utilized for gauging 916 recovery process as joint angles can be an important indicator of recovery. In some embodiments, different ranges of joint angle can be set by the clinicians during rehabilitation. The system 100 can measure the joint angle of the patient can compare with the predetermined ranges. In some embodiments, if the patient is not moving sufficiently and the joint angle measured is not within the predetermined range, the system 100 can present a feedback message to the patient indicating the same.

[0060] However, a post-operative joint may be different from a pre-operative joint due to various reasons (e.g. swelling from operation, realignment of joint, muscle degeneration with lack of usage, etc) and as such, placement of the wearable sensing device to measure the same joint may change. In these situations, recalibration will be required since the calibration formula cannot account for a difference in placement of the device without images of the changed state of the joint and/or the area surrounding the joint. Further, the calibration formula may come with a tolerance of acceptable bending change of sensing tube 12 based on the position of the device during previous calibration attempts as described by previous embodiments. A change in positioning of the device results in a change in the magnitude of bending of sensing tube 12 since the movement due to bodily segments causes either or both bodies 10 and 14 to move in different manners from previous calibration. This deviation from regular motion may also be computed as a form of tolerances of magnitude of change per change in capacitance due to bending of sensing

tube 12. Further, once change is outside of tolerance value, a warning message to the user may be sent to check that position of the wearable sensing device has not significantly changed from previous calibration. This method of detection prevents possible inaccurate measurements from occurring excessively, allowing the monitoring process to have less outliers and more meaningful results to assist clinicians in their diagnosis and understanding of their patients' recovery process.

[0061] Thus, it can be seen that a method, apparatus and system for joint angle calibration for a wearable sensing device has been disclosed which successfully and advantageously addresses the problems of the human error and complexity of the current solutions of movement monitoring and calibration in physical therapy. The method and system can be beneficial for patients who cannot perform specified joint angles required by the two-step calibration. The method and system can also reduce human error from estimating the joint angle required by the two-step calibration. Further, the method and system advantageously allows for more than one plane of rotation to be calibrated at once reducing the quantity of jobs required for the user to complete the calibration process.

[0062] While the present subject matter has been described in detail with respect to specific exemplary embodiments and methods thereof, it will be appreciated that those skilled in the art, upon attaining an understanding of the foregoing may readily produce alterations to, variations of, and equivalents to such embodiments. Accordingly, the scope of the present disclosure does not preclude inclusion of such modifications, variations and/or additions to the present subject matter as would be readily apparent to one of ordinary skill in the art. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

Claims

What is claimed is:

1. A computer-implemented method for joint angle calibration for a wearable sensing device, the wearable sensing device being attached to two segments of a user's body connected by a joint, the method comprising:
 - receiving a first and a second set of image data, the first and second set of image data corresponding to images of the two segments of the user's body and the wearable sensing device attached thereto at a first position and a second position, the first and second positions in substantially the same plane;
 - determining, using a computer vision algorithm that identifies positions of anatomical landmarks and the joint, a first joint angle between the two segments at the first position based on the first set of image data and a second joint angle between the two segments at the second position based on the second set of image data;
 - receiving raw data from the wearable sensing device, the raw data measured by the wearable sensing device coincidentally with the wearable sensing device being at the first position and being at the second position;
 - generating user-specific calibration data to calibrate the wearable sensing device based on the first and the second joint angles and the raw data from the wearable sensing device; and
 - transmitting the calibration data to the wearable sensing device for calibrating the wearable sensing device for subsequent use.
2. The method as claimed in claim 1, further comprising, after the step of transmitting the calibration data:
 - receiving, from the wearable sensing device, new raw data corresponding to the two segments of the user's body at a third position;
 - checking if the third position is in substantially the same plane with the first and second positions; and
 - if the third position is in substantially the same plane with the first and second positions, computing in real time a third joint angle between the two segments based on the new raw data using the calibration data.
3. The method as claimed in claim 2, further comprising sending a warning if the third position is not in substantially the same plane with the first and second positions.

4. The method as claimed in claim 2, further comprising presenting a feedback message if the third joint angle is not within a predetermined range.
5. The method as claimed in any one of the preceding claims, further comprising evaluating the first and the second sets of image data to determine if a quality of the image data is within an acceptable quality range based on the wearable sensing device, the anatomical landmarks, and/or the joint identified by the computer vision algorithm.
6. The method as claimed in claim 5, further comprising presenting a quality message after the step of evaluating the first and the second sets of image data.
7. The method as claimed in any one of the preceding claims, further comprising presenting visual and audio guidance on obtaining the first set of image data and/or the second set of image data within an acceptable quality range.
8. The method as claimed in any one of the preceding claims, further comprising presenting a corrected location for attaching the wearable sensing device to the two segments of the user's body connected by the joint, wherein the corrected location is based on anatomical landmarks identified by the computer vision algorithm.
9. The method as claimed in any one of the preceding claims, wherein the step of generating calibration data is by a calibration algorithm utilizing one or more of (a) image flaw correction, (b) anatomical landmark identification, and (c) pixel colour normalization.
10. The method as claimed in any one of the preceding claims, wherein the raw data comprises one or more of capacitance, voltage, current, resistance, impedance, and physical changes affected by electrical signals measured by the wearable sensing device.
11. The method as claimed in any one of the preceding claims, wherein at least one of the images corresponding to the first and the second sets of image data is captured in a plane different from the substantially same plane of the first position and the second position.
12. An apparatus for joint angle calibration for a wearable sensing device, comprising:
 - an image capturing device configured to capture an image or a video;
 - at least one processor in communication with the image capturing device; and

at least one memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus to perform the method as claimed in any one of the claims 1 to 11.

13. The apparatus as claimed in claim 12, wherein the at least one processor includes computer vision capability, and wherein the at least one memory and the computer program code are further configured to, with the at least one processor, cause the at least one processor to process the image or the video using the computer vision capability.
14. A system for joint angle calibration for a wearable sensing device, comprising:
 - a wearable sensing device configured to be attached to two segments of a user's body connected by a joint; and
 - the apparatus for joint angle calibration for the wearable sensing device as claimed in claim 12 or 13.
15. The system as claimed in claim 14, wherein the wearable sensing device comprises a first module for attaching to a first one of the two segments of the user's body and a second module for attaching to a second one of the two segments of the user's body, and wherein the first module and the second module are connected by a flexible member, the flexible member comprising a capacitor for generating the raw data when the flexible member is deformed.
16. The system as claimed in claim 14 or claim 15, wherein the system is configured to simultaneously calibrate the wearable sensing device in more than one plane of rotation.
17. A non-transitory computer readable medium having stored thereon instructions executable by a computing device to cause the computing device to perform the method as claimed in any one of the claims 1 to 11.