

COMPENSATION AWARE REHABILITATION METHOD AND SYSTEM FOR MOVEMENTS OF UPPER LIMB

Field of the Invention

5 This invention relates to a system and a method for assisting psychomotor training of individuals with movement disabilities. More particularly, this invention relates to a system and a method of detecting and reducing compensatory motions of individuals during psychomotor training. Still more particularly, this invention relates to a system and method for assisting psychomotor training of individuals with movement disabilities by
10 detecting and reducing compensatory motions of individuals' trunk and upper limbs.

Prior Art

 Spasticity is a motor disorder defined by involuntary muscle contractions, due to lesions in the central nervous system that regulated and coordinates muscle tone. It is a
15 symptom of a number of conditions such as stroke, cerebral palsy, etc. Stroke is the leading cause of disability among Singaporean adults. Each year in Singapore, approximately 10,000 people suffer stroke.

 People with spasticity, such as stroke patients, have varying levels of diminished
20 upper limb functions, which negatively affects the individual's degree of independence in activities of daily living (ADLs), mental health, and social life. Prior studies have shown that upper limb motor relearning and recovery levels tend to improve with repetitive and intensive physiotherapy delivery. The intensive task practice, in which patients actively engage in repeated attempts to produce motor behaviours beyond their present
25 capabilities, is effective for improving upper limb functions. In order to support the intensive and repetitive task practice, it is beneficial to combine the task practice with the immediate and intrinsic motivation associated with a game. An analysis of the properties

of gaming in the context of the needs of stroke patients suggests that it is an important and feasible approach. It is known that games have been developed for upper limb rehabilitation purposes, which use the Kinect to track the limb's motion to play the game. The results found the feasibility of using Kinect-based games to improve the arm movement speed to decrease spasticity.

One abnormal movement observed in the intensive task practice of motor training, either in the traditional rehabilitation or with the support of game, is the compensatory motion. For example, when doing the reaching rehabilitation task, the compensatory motions include shoulder abduction and internal rotation, and flexion/rotation of the torso. These compensatory motions can impede the progress toward to the upper limb recovery.

The traditional method is that therapists closely monitor patient's training and correct the compensation once they see compensatory motions. However, it is always a challenge for a therapist to spend time on monitoring patient's repetitive task practice, especially when the clinic and/or care centre meet the shortage of therapists. The research on helping patients to reduce compensation is still limited so far. The majority of efforts only enable therapeutic exercise without evaluating exercise correctness.

Recent studies explore the use of technology to reduce compensation in upper limb rehabilitation. One known method uses torso restraints to physically prevent compensation, and detecting forward torso compensation using a pressure sensor on a chair and providing audible feedback in response. However, the pressure sensor approach can only detect forward torso compensation and has no tolerance. Another known method uses Wii remote devices to detect exercise and compensation separately and developed a method to prevent players from making the game easier through compensation. However the method did not actively help them learn not to compensate.

These approaches can actively detect the compensation and give feedback via audio or visual channels.

The approach using robotics to reduce compensation is now observed in hospitals.

5 The robot-aided therapy can reduce the compensatory motion as well as underline the impact of intensive and repetitive practices in the upper limb rehabilitation. As the paralyzed limb is usually constrained on the robotics device, it is difficult for patients to compensate the limb motion. Thus the training is “errorless” since the robotic devices can guide the paralyzed limb to correctly complement the voluntary movement for each
10 attempt. The robotic assistive device is often coupled with Virtual Reality or game interactive environment to provide multiple sensory inputs and feedbacks in motor training, such as the MIT-Manus robotic-based therapeutic system used in hospitals.

Hence, those skilled in the art are striving to provide an improved system and
15 method that can assist psychomotor training of individuals with movement disabilities.

Summary of the Invention

The above and other problems are solved and an advance in the art is made by compensation-aware rehabilitation system in accordance with this invention. A first
20 advantage of a compensation-aware rehabilitation system in accordance with this invention is that the compensation-aware rehabilitation system is easy to install and operate. This allows the system to be used in a variety of places, including clinic, nursing home, elderly care centre, and even at home. A second advantage of a compensation-aware rehabilitation system in accordance with this invention is that the compensation-
25 aware rehabilitation system allows monitoring of patient’s performances with minimal supervision by a therapist. This increases productivity as therapist can attend to more patients. A third advantage of a compensation-aware rehabilitation system in accordance

with this invention is that the compensation-aware rehabilitation system provides a variety of stimulus and entertainments in the game-based application to sustain the patient's interests to complete the practice.

5 In accordance with an aspect of the invention, a compensation-aware rehabilitation system and method for assisting psychomotor training of an individual with movement disabilities is provided in the following manner. First, the method provides a calibration procedure. Subsequently, the method initiates a game session. A game session is a duration of a game having a number of game tasks. Each game task
10 comprises capturing a motion data of the individual, determining a compensatory motion of the individual, determining a compensation strategy based on the determined compensatory motion of the individual, adjusting a next game task according to the determined compensation strategy, and recording a performance of the individual. The method then determines whether the game session has completed and repeats the step
15 for next game task in response to the game session has not been completed. If the game session has completed, the method display the performance of the individual. The performance is a hand trajectory captured by a gesture-based camera and the motion data are orientation and position of seven joints of the individual.

20 In accordance with an embodiment of the invention, the calibration procedure is provided in the following manner. The method displays a posture sample and obtains motion data of individual capture from the gesture-based camera. The method then determines a best match motion data in the following manner. The method retrieves a number of standard motion data and compares the motion data of the individual with each
25 of the standard motion data. The method then determines the best match motion data based on one of the motion data of the individual being the closest match to the standard motion data.

In accordance with an embodiment of the invention, the compensatory motion is determined in the following manner. The method determines angle differences between each of the seven joints in motion data with respective joints in the determined best match motion data. The method then normalises each of the determined differences to a value between 0 and 1, and determines total differences of all seven joints. Subsequently, the method compares the total differences with a predetermined threshold and determines a compensatory motion in response to the total difference being more than the predetermined threshold.

In accordance with an embodiment of the invention, each of the angle differences between each of the seven joints in motion data and respective joints in the determined best match motion data is determined with the following expression,

$$A = \arccos (P_x \times S_x + P_y \times S_y + P_z \times S_z)$$

where P is the patient's joint orientation defined along x, y, z dimensions as Px, Py, Pz, and S is the best-matched joint orientation defined along x, y, z dimensions as Sx, Sy, Sz.

In accordance with an embodiment of the invention, the angle differences are normalised in the following manner. If the angle difference is more than 60 degrees, the value of the difference is assigned as 1. If the angle difference is 0 degree, the value of the difference is assigned as 0. If the angle difference is between 0 and 60 degrees, value is normalised with the following expression,

$$V = 1 - (60 - A) / 100$$

where A is the angle difference between two orientations, V is the value of difference.

In accordance with an embodiment of the invention, the total difference of all seven joints is determined with the following expression,

$$V_t = V_1 \times 40\% + (V_2 + V_3) \times 30\% + (V_4 + V_5) \times 20\% + (V_6 + V_7) \times 10\%$$

where V1 is the orientation difference value of Shoulder Centre; V2 and V3 are the orientation difference value of left and right shoulder, respectively; V4 and V5 are the orientation difference value of left and right elbow, respectively; and V6 and V7 are the orientation difference value of left and right wrist, respectively.

In accordance with an embodiment of the invention, the compensation strategy is determined in the following manner. The method reads the difference of shoulder centre and compares the angle difference of said shoulder centre with a predetermined threshold. The method then determines a forward orientation, PF, in response to the difference of shoulder centre being above the predetermined threshold and determines the forward orientation, SF, obtainable during calibration procedure. The method then determines and normalises the angle difference of PF and SF and compares the difference of PF and SF with a predetermined threshold. If the difference of PF and SF is above the predetermined threshold, the method determines trunk rotation.

In accordance with an embodiment of the invention, the forward orientation, PF, is determined with the following expression,

$$PF = (L_2 - L_1) \times (L_3 - L_1)$$

where L1 is the position of Shoulder Centre; L2 is the position of Left Shoulder; L3 is the position of Right Shoulder; and $\times$ is a cross operation between two vectors.

In accordance with an embodiment of the invention, the forward orientation, SF, is determined with the following expression,

$$SF = (T_2 - T_1) \times (T_3 - T_1)$$

where T1 is the position of Shoulder Centre; T2 is the position of Left Shoulder; T3 is the position of Right Shoulder; and $\times$ is a cross operation between two vectors.

In accordance with an embodiment of the invention, the angle difference of PF and SF is determined with the following expression,

$$A = \arccos (PF_x \times SF_x + PF_y \times SF_y + PF_z \times SF_z)$$

where PF is the patient's forward orientation defined along x, y, z dimensions as PF_x, PF_y, PF_z, respectively, and SF is the best-matched forward orientation in calibration defined along x, y, z dimensions as SF_x, SF_y, SF_z, respectively.

In accordance with an embodiment of the invention, the steps for determining a compensation strategy further comprises determining a position difference of shoulder centre in response to the difference of shoulder centre being below the predetermined threshold. The method compares the position difference of shoulder centre with a predetermined threshold. Preferably, the predetermined threshold is half of shoulder width. The method then determines trunk lean in response to the position difference being more than the predetermined threshold.

In accordance with an embodiment of the invention, the position difference of shoulder centre is determined with the following expression,

$$SCD = |L_1 - T_1|$$

where SCD is the distance between two Shoulder Centre positions; L1 is the position of Shoulder Centre captured by said gesture-based camera; T1 is the position of Shoulder Centre collected in calibration procedure; and $| |$ is Absolute operation on one vector.

In accordance with an embodiment of the invention, the steps for determining a compensation strategy further comprises determining three distances values between unaffected wrist joint and the affected upper limb in response to the difference of shoulder centre is below the predetermined threshold. The method then compares the three distances values with a predetermined threshold and determines limb support in response to the three distances values being less than the predetermined threshold. Preferably, the three distance values between the unaffected (left) wrist joint and the affected (right) upper limb are determined as follows: 1) determine a first distance between left and right wrist of said individual, 2) determines a second distance between left wrist and right elbow of said individual, and 3) determines a third distance between left wrist and right shoulder of said individual.

The compensation-aware rehabilitation system comprises a processing unit having a processor and a memory, a gesture-based camera, a haptic device, a display, and instructions store on said memory executed by said processor to perform the method described above.

Brief Description of the Drawings

The above and other features and advantages in accordance with this invention are described in the following detailed description and are shown in the following drawings:

Figure 1 illustrating a system in accordance with an embodiment of this invention;

Figure 2 illustrating a representative processing system in accordance with embodiments of this invention;

Figure 3 illustrating the modules of a program being executed by the system in accordance with an embodiment of this invention;

Figure 4 illustrating a configuration of the system being arranged on a moveable platform in accordance with an embodiment of this invention;

Figure 5 illustrating a flow diagram of a process performed by the system in accordance with an embodiment of this invention;

5 Figure 6 illustrating the joints of a patient being monitored in accordance with an embodiment of this invention;

Figure 7 illustrating a flow diagram of a calibration procedure in accordance with an embodiment of this invention;

Figure 8 illustrating a flow diagram of a process for determining compensatory motion in accordance with an embodiment of this invention;

Figure 9 illustrating a flow diagram of a process for determining compensation strategy in accordance with an embodiment of this invention;

Figure 10 illustrating a further flow diagram of a process for determining compensation strategy in accordance with an embodiment of this invention;

15 Figure 11 illustrating a framework to provide suitable feedback according to the determined compensation strategy in accordance with an embodiment of this invention;

Figure 12 illustrating a flow diagram of a session according to the framework in accordance with an embodiment of this invention; and

Figure 13 illustrating a further flow diagram of a process for providing suitable feedback during the session.

Detailed Description

This invention relates to a system and a method for assisting psychomotor training of individuals with movement disabilities. More particularly, this invention relates to a system and a method of detecting and reducing compensatory motions of individuals during psychomotor training. Still more particularly, this invention relates to a system and

method for assisting psychomotor training of individuals with movement disabilities by detecting and reducing compensatory motions of individuals' trunk and upper limbs.

It is envisioned that a system and a method in accordance with embodiments of this invention may be used for psychomotor training of individuals with movement disorder. In particular, the system and method assist in detecting and reducing the compensation (or compensatory motion) during psychomotor training of individuals with movement disorder. The system and method in accordance with embodiments of this invention is suitable for use in rehabilitation of patients with motor impairment of an upper limb resulting from stroke. The compensatory motions observed in the upper limb motor during training, such as the flexion/rotation of the trunk, can be detected via the system. Based on the compensatory motions detected, the system will provide suitable feedback to the patient.

The system is incorporated in a game engine to guide patients to intrinsically reduce the detected compensatory motion. In contrast to the conventional methods to command, remind or constraint patients to reduce compensatory motions, the system uses psychological technique, the operant conditioning, to trigger patient's own awareness and response to reduce compensatory motion. The trigger is done by changing feedback in the game, such as adding rewards along the trajectory of correct motor movements to induce patients to correctly move upper limb or adding undesirable "punishments" in the game to guide patient to the correct movement of upper limb. The eager and curiosity to play game successfully and to achieve a higher rating than peers may further motivate patients to reduce the detected compensatory motions. One skilled in the art will recognise that the system may be implemented in any applications other than a game engine without departing from the invention.

Figure 1 illustrates system 100 in accordance with an embodiment of this invention to assist an individual with spasticity, such as stroke patients, to train their upper limbs psychomotor skill. System 100 comprises a processing unit 110, a display 120, a haptic device 130, and a gesture-based camera 140.

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Processing unit 110 is a typical processing system such as a desktop computer, laptop computer, or other computer terminals that executes instructions to perform the application described below in accordance with this invention. Processing unit 110 is communicatively connected to display 120, haptic device 130 and gesture-based camera 140 via a wired connection. Processing unit 110 may be communicatively connected to a remote processing unit 111 via a network 115 to transmit and/or receive data from the remote processing unit 111 residing at a remote location. This allows a therapist at a remote location real-time monitoring of a training process executed by the system 100. One skilled in the art will recognise that more than one processing unit 110 may be used without departing from the invention. Further details of the processing unit 110 and 111 will be described below with reference to figure 2.

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Display 120 is a typical display such as LED display, LCD display, CRT display or the likes. Display 120 is communicatively connected to processing unit 110 to display content received from the processing unit 110.

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Haptic device 130 is a typical sensory device such as a Phantom Omni device to provide a range of haptic outputs (e.g. force and vibration) to assist the training. It is found that applying haptic sensations (e.g. force, torque, tactile, vibration) to patients during training is advantageous as this is one form of interactive communication with the patient.

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Gesture-based camera 140 is a sensor such a Kinect sensor for capturing and recognizing gestures and images, which is used to detect compensatory motions. The gesture-based camera 140 includes a webcam and a depth sensor.

Processes stored as instructions in a media that are executed by a processing system in processing unit 110 provide the method and/or system in accordance with this invention. The instructions may be stored as firmware, hardware, or software. Figure 2 illustrates processing system 200 such as the processing system in processing unit 110 and 111 that execute the instructions to perform the processes for providing a method and/or system in accordance with this invention. One skilled in the art will recognize that the exact configuration of each processing system may be different and the exact configuration of the processing system in each device may vary. Thus, processing system 200 shown in Figure 2 is given by way of example only.

Processing system 200 includes Central Processing Unit (CPU) 205. CPU 205 is a processor, microprocessor, or any combination of processors and microprocessors that execute instructions to perform the processes in accordance with the present invention. CPU 205 connects to memory bus 210 and Input/ Output (I/O) bus 215. Memory bus 210 connects CPU 205 to memories 220 and 225 to transmit data and instructions between the memories and CPU 205. I/O bus 215 connects CPU 205 to peripheral devices to transmit data between CPU 205 and the peripheral devices. One skilled in the art will recognize that I/O bus 215 and memory bus 210 may be combined into one bus or subdivided into many other busses and the exact configuration is left to those skilled in the art.

A non-volatile memory 220, such as a Read Only Memory (ROM), is connected to memory bus 210. Non-volatile memory 220 stores instructions and data needed to operate various sub-systems of processing system 200 and to boot the system at start-up. One skilled in the art will recognize that any number of types of memory may be used to perform this function.

A volatile memory 225, such as Random Access Memory (RAM), is also connected to memory bus 210. Volatile memory 225 stores the instructions and data needed by CPU 205 to perform software instructions for processes such as the processes required for providing a system in accordance with this invention. One skilled
5 in the art will recognize that any number of types of memory may be used as volatile memory and the exact type used is left as a design choice to those skilled in the art.

I/O device 230, keyboard 235, display 120, memory 245, network device 250 and any number of other peripheral devices connect to I/O bus 215 to exchange data with
10 CPU 205 for use in applications being executed by CPU 205. I/O device 230 is any devices such as the haptic device 130 and gesture-based camera 140 that transmits and/or receives data from CPU 205. Keyboard 235 is a specific type of I/O that receives user input and transmits the input to CPU 205. Display 120 receives display data from CPU 205 and display images on a screen for a user to see. Memory 245 is a device that
15 transmits and receives data to and from CPU 205 for storing data to a media. Network device 250 connects CPU 205 to a network 115 for transmission of data to and from other processing systems.

The software of the development system is a game application on Windows 7
20 platform. The game application is built based on the Unity3D platform. Figure 3 illustrates the architecture of the game-based application. The application comprises six modules as follows: Simulation module 310, Device Manager 320, Compensation Controller 330, Adaptive Controller 340, Training Setup 350, and Performance Monitor 360.

25 The Simulation module 310 simulates the designed game tasks for patients. The Device Manager 320 controls the Input/Output with third-party devices. In particular, the Device Manager 320 communicates with the gesture-based camera 140 and the haptic device 130. The Compensation Controller 330 implements the compensation-aware

rehabilitation methodology, that is, to detect compensatory motions and trigger game feedback events to guide patients to reduce the detected compensatory motions. The Adaptive Controller 340 provides adjustments to the game tasks, modifications to the detection of compensatory motion, and adjustments haptic outputs according to a variety of patient profiles and the motion abilities with each patient. A therapist can customize the game tasks via changing the rehabilitation parameters via the Training Setup 350. In other words, the game application can also receive input from the therapist. The Performance Monitor 360 records the patients' performance of executing the game tasks as well as generating a performance report for a therapist to review. The performance report can be transmitted to the therapist via email if the system 100 is deployed at patient's home. Therefore, the system 100 can be a rehabilitation tool for patients with spasticity to train at home. In other words, the system 100 can be installed at a remote location where patients can train comfortably. Further, the system 100 remotely installed at a remote location is communicatively connected to a network to allow therapist to monitor the training of the patient at real-time.

Figure 4 illustrates the processing unit 110, display 120 and gesture-based camera 140 being arranged on movable frame 410. A user sits in front of the display 120 and at about 2 meters apart from the display 120. The haptic device 130 is provided on a height adjustable table 420 for the patient to execute game tasks displayed on the display 120.

Figure 5 illustrates a flow diagram of process 500 performed by the processor in processing unit 110 in accordance with an embodiment of this invention. Process 500 is a process being executed by the game-based application upon activation of a session. For purposes of this description, a session is a training program specifically designed for training the psychomotor skill of an individual's upper-limb. Process 500 begins with step

505 where a calibration procedure is conducted to acquire the patient's own best-matched motion data compared with the standard motion data of the healthy individual. Further details of the calibration procedure will be described below with reference to figure 7.

5

After the calibration procedure, the simulation module starts the training program in step 510. The simulation module starts the training program in the following manner. The simulation module would determine the affected upper limb of the patient by reading the input provided by the patient or the therapist. One skilled in the art would recognise that the information of the patient may be stored in the database and that the simulation module may retrieve such information from the database without departing from the invention. Based on the information, the simulation module would display an image or an animation to instruct the patient to hold the haptic device using the affected upper limb. The simulation would then be displaying certain game task on the display for the patient to execute in step 510. The patient holding the haptic device attempts to execute movement according to the game-task. At this juncture, device manager also starts to receive motion data from the gesture-based camera. In particular, the gesture-based camera will capture in real time the motion data of the patient comprising the positions and orientations of seven joints of the patient. Figure 6 illustrates the positions and orientations of the seven joints, including shoulder centre 610, left shoulder 620, right shoulder 630, left elbow 640, right elbow 650, left wrist 660 and right wrist 670.

In step 515, the motion data is transmitted to the compensation controller to determine compensatory motion of the patient. Based on the motion data, process 500 determines the compensatory motion of the patient. Further details of the steps of determining compensatory motion will be described below with reference to figure 8.

In step 520, process 500 determines a compensation strategy according to the compensatory motion determined in step 515. Further details of the steps of determining compensation strategy will be described below with reference to figures 9 and 10.

5 In step 525, the compensation strategy is transmitted to the adaptive controller that will adjust the game task. Further details of the steps of determining compensation strategy will be described below with reference to figure 11.

During steps 510-525, the performance monitor records the patient's performance.

10 In particular, the performance monitor records and visualises the hand trajectory captured by the gesture-based camera 140. A therapist can justify a patient's recovery progress based on the recorded and visualised hand trajectory. A patient's hand trajectory that is in accordance with the required trajectory suggests that the patient regain the motor capability to control the upper limb.

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In step 530, training session ends and the performance of the patient recorded by the performance monitor will be displayed. Process 500 ends after step 530.

Calibration procedure

20 Figure 7 illustrates a flow diagram of process 700 performed by the processor in processing unit 110 in accordance with an embodiment of this invention. Process 700 is a process being executed by the game-based application to calibrate the upper limbs of the patient to a standard motion data collected from the healthy individuals. The standard motion data are collected from selected healthy individuals using the same game-based
25 application and stored on the memory of the processing unit 110. In other words, the standard motion data of selected healthy individuals are collected during system

development. The standard motion data comprises the orientation and position of the seven joints.

Process 700 begins with step 705 by displaying a posture sample on display. In particular, the posture sample is retrieved from the memory of the processing unit 110 and displayed on the display. The patient will try his/her best to mimic the posture sample. The posture sample is a posture that is also performed by the selected healthy individuals when collecting standard motion data.

In step 710, device manager starts to receive motion data from the gesture-based camera. In particular, the gesture-based camera will capture in real time the motion data of the patient comprising the positions and orientations of seven joints of the patient.

Given the limited range of motion with the patient, the patient may not fully and accurately mimic the posture sample as displayed on the display. Hence, in step 715, process 700 compares the motion data of the patient with the standard motion data and determines the 'best match'. In particular, the "best match" is determined by comparing each of the motion data of the patient with the standard motion data. The one that best matches the standard motion data is determined as the best match standard motion data. One skilled in the art will recognise that the best match may be determined by a therapist without departing from the invention. Process 700 ends after step 715.

Determine compensatory motion

Figure 8 illustrates a flow diagram of process 800 performed by the processor in processing unit 110 in accordance with an embodiment of this invention. Process 800 is a process being executed by the game-based application to determine compensatory motion. Process 800 begins with 805 by capturing the real-time motion data of the patient.

Process 800 will then compare and determine the differences between the motion data of the patient and the determined best-matched motion data in step 810.

The comparison between the real-time motion data and the patient's own best-matched motion data can be more effective to detect compensatory motion than the comparison between the real-time motion data and the standard motion data collected from the healthy individual, as the former comparison can better prevent the fake detection of compensatory motion. A patient with spasticity usually has limited range of motion with one or some of the seven joints. If the motion data of these joints are compared to the standard motion data, it would likely be wrongly detected as the compensatory motion.

The differences of one joint between the motion data of the patient and the determined best-matched motion data are determined with the following expression:

$$A = \arccos (P_x \times S_x + P_y \times S_y + P_z \times S_z) \quad (1)$$

Where A is the angle difference, P is the patient's joint orientation defined along x, y, z dimensions as P_x , P_y , P_z , respectively, and S is the best-matched joint orientation defined along x, y, z dimensions as S_x , S_y , S_z , respectively. Equation (1) is repeated for each of the seven joints.

In step 815, the difference between two orientations will be normalized into the range from 0 to 1. In particular, if there is no difference between two orientations, the value will be 0. If the difference between two orientations is more than 60 degrees, the value will be 1. When the difference between two orientations is between 0 and 60 degrees, the value will be calculated via the following expression:

$$V_i = 1 - (60 - A_i) / 100 \quad (2)$$

Where A_i is the angle difference between two orientations, V_i is the value of
 5 difference, and i is the relevant joint.

In step 820, process 800 determines the total difference of seven joints with the
 following expression:

$$V = V_1 \times 40\% + (V_2 + V_3) \times 30\% + (V_4 + V_5) \times 20\% + (V_6 + V_7) \times 10\% \quad (3)$$

Where V_1 is the orientation difference value of Shoulder Centre; V_2 and V_3 are
 the orientation difference value of left and right shoulder, respectively; V_4 and V_5 are the
 orientation difference value of left and right elbow, respectively; and V_6 and V_7 are the
 15 orientation difference value of left and right wrist, respectively.

In step 825, the total difference is compared with a threshold. If the total difference
 is larger than the threshold, process 800 determines that there is compensatory motion in
 step 830. If the total difference is not larger than the threshold, process 800 repeats from
 20 step 801. The threshold for this example is 0.8. However, one skilled in the art will
 recognise that other threshold value may be implemented without departing from the
 invention. Process 800 ends after step 830.

Figure 9 illustrates a flow diagram of process 900 performed by the processor in
 25 processing unit 110 in accordance with an embodiment of this invention. Process 900 is
 a process being executed by the game-based application to determine compensation

strategy. It is note that three compensation strategies are frequently observed in the upper-limb rehabilitation and they are as follows:

1. Trunk rotation: Where the patient rotates the trunk to one side (e.g. the left side) to pull the affected upper limb to the rotating side so that the affected upper limb can drag the game controller (i.e. haptic device)
2. Trunk lean: Where the patient leans the body trunk to one side (e.g. left side) to pull the affected upper limb to the leaning side so that the affected upper limb can drag the game controller (i.e. haptic device)
3. Limb support: the patient uses the unaffected upper limb to compensate the horizontal or vertical motion of the affected upper limb.

Process 900 begins with 905 with reading the value of the orientation difference, V1, of Shoulder Centre. The orientation difference value of Shoulder Centre, V1, is compared with a threshold in step 910. If V1 is not greater than the threshold, process 900 proceeds to step 912 to determine whether there is trunk lean or limb support compensation. Further details pertaining to the process of determining trunk lean or limb support will be described below with reference to figure 1000. If V1 is greater than the threshold, process 900 will continue with step 915 to determine the patient's forward orientation (PF) during game-play via the following expression:

$$PF = (L_2 - L_1) \times (L_3 - L_1) \quad (4)$$

Where L1, L2, L3 are the position data collected during game-play. L1 is the position of Shoulder Centre; L2 is the position of Left Shoulder; L3 is the position of Right Shoulder; and $\times$ means Cross operation between two vectors.

In step 920, process 900 determines the forward orientation (SF) in calibration via the following expression:

$$SF = (T_2 - T_1) \times (T_3 - T_1) \quad (5)$$

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Where T1, T2, T3 are the position data collected during calibration procedure; T1 is the position of Shoulder Centre; T2 is the position of Left Shoulder; T3 is the position of Right Shoulder; and $\times$ means Cross operation between two vectors.

10 The forward orientation is actually the direction a patient faces the display displaying the game-based application. In step 925, the difference between these two forward orientations will be calculated via the following expression:

$$A = \arccos (PF_x \times SF_x + PF_y \times SF_y + PF_z \times SF_z) \quad (6)$$

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Where A is the angle difference, PF is the patient's forward orientation defined along x, y, z dimensions as PF_x, PF_y, PF_z, respectively, and SF is the best-matched forward orientation taken during calibration procedure defined along x, y, z dimensions as SF_x, SF_y, SF_z, respectively.

20

Then the difference of these two forward orientations, PF and SF will be normalized into the range from 0 to 1 via the following expression:

$$V = 1 - (60 - A) / 100 \quad (7)$$

25

Where A is the angle difference between PF and SF, and V is the value of difference.

In step 930, if the value of difference, V, is larger than a predetermined threshold, process 900 determines that the compensation strategy is Trunk Rotation in step 935. Otherwise, process 900 reports no compensation strategy found in step 940. Process 900 ends after step 935 or 940.

Figure 10 illustrates a flow diagram of process 1000 performed by the processor in processing unit 110 in accordance with an embodiment of this invention. Process 1000 is a process of determining trunk lean or limb support in step 912 in process 900. Process 1000 begins with step 1005 by determining the position difference of shoulder centre. The position of Shoulder Centre (L1) collected during game-play will be compared with the position data of the same joint (T1) collected in calibration via the following expression:

$$SCD = |L_1 - T_1| \quad (8)$$

Where SCD is the distance between two Shoulder Centre positions; L1 is the position of Shoulder Centre collected during game-play; T1 is the position of Shoulder Centre collected in calibration; and $| |$ means Absolute operation on one vector.

In step 1010, process 1000 will compare the difference between the two positions of Shoulder Centre, SCD, with a predetermined threshold value. The predetermined threshold value is typically half of shoulder width. If the absolute difference between the two positions of Shoulder Centre is larger than the half of shoulder width, then the compensation strategy will be determined as the trunk lean in step 1015. Further, if the difference between the two positions of Shoulder Centre is positive, the trunk lean is to the left. If the difference between the two positions of Shoulder Centre is negative, the

trunk lean is to the right. One skilled in the art will recognise that left or right trunk lean is dependent on the orientation of the patient. Hence, alternatively, the process may be configured to determine a trunk lean to the right for a positive difference between the two positions of Shoulder Centre and a trunk lean to the left for a negative difference between the two positions of Shoulder Centre without departing from the invention. Otherwise, process 1000 will proceed to step 1020.

In step 1020, process 1000 determines three distance values between the unaffected wrist joint and the affected upper limb. For example, the affected (paralysed) upper limb is the right upper limb and the left upper limb is the unaffected limb. Three values can be determined based on the distances between the left wrist and the right upper limb as follows: 1) the distance between the left wrist and the right wrist; (2) the distance between the left wrist and the right elbow; and (3) the distance between the left wrist and the right shoulder.

In step 1025, if any one of the three distance values is less than a predetermined threshold, the unaffected left upper limb will be considered to support the affected right upper limb for compensation and thus determined to be Limb Support in step 1030. If all three distance values are more than the predetermined threshold, process 1000 proceeds to step 1035 to report no compensation strategy found. Process 1000 ends after step 1030 or 1035.

Adjust level of program

Figure 11 illustrates a framework 1100 for adjusting game task according to compensation strategy in step 525 in process 500. The framework 1100 is for implementing suitable feedbacks during training based on the determined compensation

strategy for the currently developed game. The feedbacks aim to guide the patient to reduce the detected compensatory motions when the patient responds to the feedback.

Briefly, the current developed game involves coins falling from the top of display to bottom of the display. Further, the coins are randomly falling between the left and right sides of the display when there is no detected compensatory motion from patient. Proximate the bottom of the screen includes a character. The character is the target game object controlled by the patient via haptic device. The game task is such that the patient controls the movement of the character by moving the haptic device left or right. Particularly, moving the haptic device left causes the character in game to move to the left and moving the haptic device right causes the character to move to the right. During the course of the game, bombs or treasure boxes may be included. Essentially, the game task is to move the character to a position to collect coins and treasure boxes and to avoid the bomb.

The framework 1100 proposes three guidelines to implement the feedback. These guidelines are devised based on the operant conditioning, a behavioural psychology technique that can modify human motor behaviour through reward and punishment and they are as follows:

- 1) Changing behaviour of the target game object.
- 2) Adding additional game objects into game scenario.
- 3) Increasing or decreasing grades to differentiate the desired and undesired motion.

The first guideline 1110 focuses on punishment to the undesired compensatory motion. The target game object is controlled by the patient with spasticity (e.g. the stroke

patient) via haptic device to accomplish the game task in game scenario. The change of target game object behaviour may give additional challenges for patient to accomplish the game task. Thus the player needs to reduce or overcome the compensatory motion in the gameplay. In the currently developed game, this guideline is implemented by changing the size of the target game object, the character controlled by patient.

The second guideline 1120 focuses on the positive punishment to the patient's compensatory motions. The additional game objects will be appeared once the compensatory motions are detected during game-play, which may strengthen player's response or intention to move upper limb in correct ways as well as overcome the compensation. In the currently developed game, this guideline is implemented by setting additional coins to fall at specific positions between the left and right of the display to induce player to play game correctly.

The third guideline 1130 is to indicate the performance on adapting to the correct movement of upper limb. For example, increasing grades is to reward the desired motion in accomplishing game task, whilst decreasing grades to punish the undesired motion. In the currently developed game, this is done by adding treasure boxes to assist in increasing grades while bombs are added to motivate players to adapt the correct movement.

Besides the feedback as disclosed in the above three guidelines, the text and audio feedbacks are added into game-play to increase the awareness of compensation. The detection of compensatory motion triggers the game application to play a new audio (different from the background music) as well as display the instruction text on screen, and thus the player can be easily aware of compensatory motion.

The framework 1100 illustrates the eight feedbacks designed in the currently developed game. Time bar 1160 indicates the duration of a game scenario. The first column indicates the compensation strategy 1140 determined while the second column indicate the feedback 1150 in response to the determined compensation strategy. Six of these eight feedbacks (that is, feedback 2 to 7) are designed based on the above three guidelines to support players to reduce compensatory motion. Specifically, the feedback 2 and feedback 3 are based on the first guideline 1110 to change the behaviour of target game objects; feedback 4 and feedback 5 are based on the second guideline 1120 to add additional game objects; and feedback 6 and feedback 7 are based on the third guideline 1130 to increasing or decreasing grades.

It should be noted that feedback 1 and feedback 8 are not designed to overcome compensatory motions but to support players to play the game in an easy manner as well as promote their interests in completing game tasks. It should be also noted that feedback 6 and feedback 7 are to cater for the conditions when the compensation strategy is not reported during the course of the game.

Figure 12 illustrates a flow process of an exemplary process 1200 that incorporates the processes described above in a game-based application. Process 1200 is performed by the processor in processing unit 110 in accordance with an embodiment of this invention. Process 1200 is an exemplary process in accordance with the framework 11. The design of game-based application is based on the typical practice of motor training in rehabilitation. In particular, the aim of the game-based application is to control the movement of a character to collect coins falling between left and right sides of screen. To move the character between left and right sides of screen, the patient needs to repeatedly move one upper limb on the horizontal dimension to control the handle of haptic device via hand. The repeated upper limb movement on the horizontal dimension,

for example moving hand to left side of body and return to the right side of body, is actually one practice of motor training. It is important to note that the movement of whole upper limb is moved with the shoulder joint as the pivot. The completion of a game task in the game-based application means that the character manages to collect one coin falling at the left or right side of screen. In motor training, the completion of a game task means that a patient can move the upper limb on the horizontal dimension so as to move hand to the left or right side of body. The movement of upper limb might be compensated by the other body part, e.g. the trunk rotation, which needs to be overcome in motor training. The completion of a game task without compensatory motion suggests that a patient can control the upper limb's movement on the horizontal dimension, without supports from other body parts.

Process 1200 begins with step 1205 by requesting registration in order to obtain information pertinent to the patient. One such information is the registration number of the patient. One skilled in the art will recognise that other information that is associated to the patient may be requested without departing from the invention.

Based on the information obtained in step 1205, process 1200 retrieves information associated to the registration number from the memory in step 1210. The information includes name, affected upper limbs, medical condition, performance record, etc.

In step 1215, process 1200 proceeds with the calibration procedure as described in step 505 in process 500.

After the calibration procedure, process 1200 starts a game session by initiating a task in step 1220. The task in this instance is dropping a coin or a group of coins

randomly along the width of the display. Further details of initiating a task would be described below with reference to figure 13.

5 In step 1222, process 1200 records the performance of the patient via the performance monitor 360. The performance monitor 360 in this game-based application is mainly to record and visualise the hand trajectory captured by the gesture-based camera.

10 In step 1225, process 1200 determines whether the game session has completed. If the game session has not completed, process 1200 repeats step 1220 and continues with the next task. Otherwise, process 1200 proceeds to step 1230 to record the performance of the patient.

15 In step 1230, process 1200 displays the performance of the patient. A therapist can justify a patient's recovery progress based on the recorded and visualised hand trajectory. A patient's hand trajectory that is in accordance with the required trajectory suggests that the patient regain the motor capability to control the upper limb. In particular at the current game-based application, the required hand trajectory is a line on the XY plane. Process 1200 ends after step 1230.

20 Figure 13 illustrates a flow diagram of process 1300 performed by the processor in processing unit 110 in accordance with an embodiment of this invention. Process 1300 is a process of initiating a task in step 1220 in process 1200. Process 1300 begins with step 1305 by resetting a counter to zero.

25 In step 1310, process 1300 drops a coin or a group of coins randomly between the left and right sides of the screen. As a warm up, coins continue to be dropped at random locations for at least the initial 10% of the duration of the game. Hence in step

1315, process 1300 determines whether the game has passed the initial 10% of the game. If the game has passed the initial 10% of the game, process 1300 proceeds to step 1320. Otherwise, process 1300 repeats step 1310.

5 In step 1320, process 1300 determines whether the game has passed 90% of the duration of the game. This is to promote the patient's interests in completing the game. If the game passes 90% of the duration of the game, process 1300 proceeds to step 1325 and continue to drop coins randomly until the end of the game. Otherwise, process 1300 proceeds to step 1330.

10

 In step 1330, process 1300 capture motion data in accordance with step 510 in process 500.

 In step 1335, process 1300 determines movement of the patient. If the patient
15 remain stationary, process 1300 proceeds to step 1380 to add bomb above the character and drop coins at a location away from the bomb. This is to force the patient to move the character away from the bomb and towards the coins. One skilled in the art will recognise that alternatively, any movement received from the haptic device may determine the movement of the patient. Particularly, if the haptic device is almost the same (the
20 changes of input is not bigger than a predetermined value) for continual 5 seconds, then the game-based application will determine that the patient does not move the haptic device and add bomb above the character.

 After step 1380, process 1300 repeats from step 1320. If process 1300
25 determines movement of the patient, process 1300 proceeds to step 1340.

In step 1340, process 1300 determines whether the character manages to collect the coin. If the character manages to collect the coin, process 1300 proceeds to step 1350 to increase the counter by one. If the character did not manage to collect the coin, process 1300 proceeds to step 1370.

5

In step 1355, process 1300 determines whether the counter is more than 4. If the counter is more than 4, process 1300 proceeds to step 1360. Otherwise, process 1300 proceeds to step 1370.

10

In step 1360, process 1300 adds treasure boxes and resets the counter to zero. After step 1360, process 1300 proceeds to step 1370.

15

In step 1370, process 1300 determines compensatory motion in accordance with step 515 in process 500. In step 1375, if compensatory motion is detected, process 1300 proceeds to step 1385 to determine the compensatory strategy in accordance with step 520 in process 500. If compensatory motion is not detected, process 1300 proceeds to step 1390 and continue to drop coin in step 1390. After step 1390, process 1300 repeats from step 1320.

20

In step 1395, process 1300 adjusts the game task according to the determined compensation strategy in accordance with step 525 in process 500. In particular, if the compensation strategy is trunk rotate, the size of the character is increased. If the compensation strategy is limb support, the size of the character is decreased. If the compensation strategy is trunk lean to the left, coins would be added to the left side of the display. If the compensation strategy is trunk lean to the right, coins would be added to the right side of the display. After step 1395, process 1300 proceeds to step 1390.

25

It is noted that during the game session, process 1300 may activate the device manager 320 to trigger haptic pulses to the haptic device 130.

5 The above is a description of exemplary embodiments of a system and method in accordance with this invention. It is foreseeable that those skilled in the art can and will design alternative systems based on this disclosure that infringe upon this invention as set forth in the following claims.

Claims:

1. A compensation-aware rehabilitation system for assisting psychomotor training of an individual with movement disabilities comprising:

- 5 a processing unit having a processor and a memory;
a gesture-based camera;
a haptic device;
a display; and
instructions store on said memory executed by said processor to:
- 10 provide a calibration procedure;
initiate a game session comprising:
initiate a game task comprising:
capture motion data of said individual via said gesture-
based camera,
15 determine a compensatory motion of said individual,
determine a compensation strategy based on said
determined compensatory motion of said individual,
adjust a next game task according to said determined
compensation strategy,
20 record a performance of said individual in said memory;
determine whether said game session has completed,
repeat said instruction to initiate said game task for next game task
in response to said game session has not been completed,
display said performance of said individual on said display in response to
25 said completion of said game session.

2. The system according to claim 1 wherein said instruction to record a performance of said individual comprises instructions to:

record a hand trajectory captured by said gesture-based camera.

5 3. The system according to claim 1 wherein said motion data comprises orientation and position of seven joints of said individual.

4. The system according to claim 1 wherein said instruction to provide a calibration procedure comprises instructions to:

10 display a posture sample stored on said memory of said processing unit;
obtain motion data of individual from said gesture-based camera; and
determine a best match motion data.

5. The system according to claim 4 wherein said instruction to determine said best match comprises instructions to:

15 retrieve a standard motion data from said memory;
compare each of said motion data of said individual with said standard motion data; and
determine said best match motion data based on one said motion data of said
20 individual being the closest to said standard motion data.

6. The system according to claim 5 wherein said motion data comprises orientation and position of seven joints of said individual.

25 7. The system according to claim 6 wherein said instruction to determine a compensatory motion of said individual comprises instructions to:

$$V = 1 - (60 - A) / 100$$

where A is the angle difference between two orientations, and V is the value of difference.

- 5 10. The system according to claim 9 wherein said instruction to determine total differences of all seven joints comprises instructions to:

determine total differences, V_t , of all seven joints with the following expression,

$$V_t = V_1 \times 40\% + (V_2 + V_3) \times 30\% + (V_4 + V_5) \times 20\% + (V_6 + V_7) \times 10\%$$

- 10 where V_1 is the orientation difference value of Shoulder Centre; V_2 and V_3 are the orientation difference value of left and right shoulder, respectively; V_4 and V_5 are the orientation difference value of left and right elbow, respectively; and V_6 and V_7 are the orientation difference value of left and right wrist, respectively.

- 15 11. The system according to claim 10 wherein said instruction to determine a compensation strategy comprises instructions to:

read the difference of shoulder centre;

compare said angle difference of said shoulder centre with a predetermined threshold;

- 20 determine a forward orientation, PF, in response to said difference of shoulder centre being above said predetermined threshold;

determine forward orientation, SF, during calibration procedure;

determine and normalise angle difference of PF and SF;

compare said difference of PF and SF with a predetermined threshold;

- 25 determine trunk rotation in response to said difference of PF and SF being above said predetermined threshold.

12. The system according to claim 11 wherein said forward orientation, PF, is determined with the following expression,

$$PF = (L_2 - L_1) \times (L_3 - L_1)$$

where L1 is the position of Shoulder Centre; L2 is the position of Left Shoulder; L3

5 is the position of Right Shoulder; and $\times$ is a cross operation between two vectors.

13. The system according to claim 12 wherein said forward orientation, SF, is determined with the following expression,

10

$$SF = (T_2 - T_1) \times (T_3 - T_1)$$

where T1 is the position of Shoulder Centre; T2 is the position of Left Shoulder; T3 is the position of Right Shoulder; and $\times$ is a cross operation between two vectors.

14. The system according to claim 13 wherein said angle difference of PF and SF is determined with the following expression,

15

$$A = \arccos (PF_x \times SF_x + PF_y \times SF_y + PF_z \times SF_z)$$

where PF is the individual's forward orientation defined along x, y, z dimensions as PF_x, PF_y, PF_z, respectively, and SF is the best-matched forward orientation defined along x, y, z dimensions as SF_x, SF_y, SF_z, respectively.

20

15. The system according to claim 14 wherein said instruction to normalise said angle difference of PF and SF comprises instructions to

assign said value of said angle difference as 1 in response to said angle difference being more than 60 degrees;

25 assign said value of said angle difference as 0 in response to said angle difference being 0; and

determine said value with the following expression in response to said angle difference being between 0 and 60 degrees,

$$V = 1 - (60 - A) / 100$$

where A is the angle difference between PF and SF, V is the value of difference.

5

16. The system according to claim 15 wherein said instructions to determine a compensation strategy further comprises instructions to:

determine position difference of shoulder centre in response to said difference of shoulder centre being below said predetermined threshold;

10 compare said position difference of shoulder centre with a predetermined threshold, said predetermined threshold being half of shoulder width; and

determine trunk lean in response to said position difference being more than said predetermined threshold.

15 17. The system according to claim 16 wherein said position difference of shoulder centre is determined with the following expression,

$$SCD = | L_1 - T_1 |$$

where SCD is the distance between two Shoulder Centre positions; L1 is the position of Shoulder Centre captured by said gesture-based camera; T1 is the position of
20 Shoulder Centre collected in calibration procedure; and | | is Absolute operation on one vector.

18. The system according to claim 17 wherein said instruction to determine a compensation strategy further comprises instructions to:

25 determine three distances values between unaffected wrist joint and the affected upper limb in response to said difference of shoulder centre being below said predetermined threshold;

compare said three distances values with a predetermined threshold; and
determine limb support in response to said three distances values being less than
said predetermined threshold.

5 19. The system according to claim 18 wherein said instruction to determine three
distances values between unaffected (left) wrist joint and the affected (right) upper limb in
response to said difference of shoulder centre being below said predetermined threshold
comprises instructions to:

determine a first distance between left and right wrist of said individual,
10 determine a second distance between left wrist and right elbow of said individual;
and
determine a third distance between left wrist and right shoulder of said individual.

20. A method for assisting psychomotor training of an individual with movement
15 disabilities, said method comprising:

providing a calibration procedure;
initiating a game session comprising:
initiating a game task comprising:
capturing motion data of said individual via said gesture-based
20 camera,
determining a compensatory motion of said individual,
determining a compensation strategy based on said determined
compensatory motion of said individual,
adjusting a next game task according to said determined
25 compensation strategy,
recording a performance of said individual in said memory;
determining whether said game session has completed,

repeating said step to initiate said game task for next game task in response to said game session has not been completed, displaying said performance of said individual on a display in response to said completion of said game session.

5

21. The method according to claim 20 wherein said step of recording a performance of said individual comprises:

recording a hand trajectory captured by said gesture-based camera.

10 22. The method according to claim 20 wherein said motion data comprises orientation and position of seven joints of said individual.

23. The method according to claim 20 wherein said step of providing a calibration procedure comprises:

15 displaying a posture sample stored on said memory of said processing unit;
obtaining motion data of said individual from said gesture-based camera; and
determining a best match motion data.

20 24. The method according to claim 23 wherein said step of determining said best match comprises:

retrieving a standard motion data from said memory;

comparing each of said motion data of said individual with said standard motion data; and

25 determining said best match motion data based on one said motion data of said individual being the closest to said standard motion data.

25. The method according to claim 24 wherein said motion data comprises orientation and position of seven joints of said individual.

26. The method according to claim 25 wherein said step of determining a compensatory motion of said individual comprises:

determining angle differences between each of said seven joints in motion data with respective joints in said determined best match motion data;

normalising each of said determined differences to a value between 0 and 1;

determining total differences of all seven joints;

comparing said total differences with a predetermined threshold; and

determining a compensatory motion in response to said total difference being more than said predetermined threshold.

27. The method according to claim 26 wherein said step of determining angle differences between each of said seven joints in motion data with respective joints in said determined best match motion data comprises:

determining each of said angle differences, A, between each of said seven joints in motion data with respective joints in said determined best match motion data with the following expression,

$$A = \arccos (P_x \times S_x + P_y \times S_y + P_z \times S_z)$$

where P is the individual's joint orientation defined along x, y, z dimensions as Px, Py, Pz, and S is the best-matched joint orientation defined along x, y, z dimensions as Sx, Sy, Sz.

28. The method according to claim 27 wherein said step of normalising each of said determined differences to said value between 0 and 1 comprises:

assigning said value of said difference as 1 in response to said angle difference being more than 60 degrees;

assigning said value of said difference as 0 in response to said angle difference being 0; and

5 determining said value with the following expression in response to said angle difference being between 0 and 60 degrees,

$$V_i = 1 - (60 - A_i) / 100$$

where A_i is the angle difference between two orientations, V_i is the value of difference and $i = 1$ to 7.

10

29. The method according to claim 28 wherein said step of determining total differences of all seven joints comprises:

determining total differences, V_t , of all seven joints with the following expression,

$$V_t = V_1 \times 40\% + (V_2 + V_3) \times 30\% + (V_4 + V_5) \times 20\% + (V_6 + V_7) \times 10\%$$

15

where V_1 is the orientation difference value of Shoulder Centre; V_2 and V_3 are the orientation difference value of left and right shoulder, respectively; V_4 and V_5 are the orientation difference value of left and right elbow, respectively; and V_6 and V_7 are the orientation difference value of left and right wrist, respectively.

20

30. The method according to claim 29 wherein said step of determining a compensation strategy comprises:

reading the difference of shoulder centre;

comparing said angle difference of said shoulder centre with a predetermined

25 threshold;

determining a forward orientation, PF, in response to said difference of shoulder centre being above said predetermined threshold;

determining forward orientation, SF, during calibration procedure;
determining and normalising angle difference of PF and SF;
comparing said difference of PF and SF with a predetermined threshold;
determining trunk rotation in response to said difference of PF and SF being
5 above said predetermined threshold.

31. The method according to claim 30 wherein said forward orientation, PF, is determined with the following expression,

$$PF = (L_2 - L_1) \times (L_3 - L_1)$$

10 where L1 is the position of Shoulder Centre; L2 is the position of Left Shoulder; L3 is the position of Right Shoulder; and $\times$ is a cross operation between two vectors.

32. The method according to claim 31 wherein said forward orientation, SF, is
15 determined with the following expression,

$$SF = (T_2 - T_1) \times (T_3 - T_1)$$

where T1 is the position of Shoulder Centre; T2 is the position of Left Shoulder; T3 is the position of Right Shoulder; and $\times$ is a cross operation between two vectors.

20 33. The method according to claim 13 wherein said angle difference of PF and SF is determined with the following expression,

$$A = \arccos (PF_x \times SF_x + PF_y \times SF_y + PF_z \times SF_z)$$

where PF is the individual's forward orientation defined along x, y, z dimensions as PF_x, PF_y, PF_z, respectively, and SF is the best-matched forward orientation defined
25 along x, y, z dimensions as SF_x, SF_y, SF_z, respectively.

34. The method according to claim 33 wherein said step of normalising said angle difference of PF and SF comprises:

assigning said value of said angle difference as 1 in response to said angle difference being more than 60 degrees;

5 assigning said value of said angle difference as 0 in response to said angle difference being 0; and

determining said value with the following expression in response to said angle difference being between 0 and 60 degrees,

$$V = 1 - (60 - A) / 100$$

10 where A is the angle difference between PF and SF, V is the value of difference.

35. The method according to claim 34 wherein said step of determining a compensation strategy further comprises:

15 determining position difference of shoulder centre in response to said difference of shoulder centre being below said predetermined threshold;

comparing said position difference of shoulder centre with a predetermined threshold, said predetermined threshold being half of shoulder width; and

determining trunk lean in response to said position difference being more than said predetermined threshold.

20

36. The method according to claim 35 wherein said position difference of shoulder centre is determined with the following expression,

$$SCD = |L_1 - T_1|$$

25 where SCD is the distance between two Shoulder Centre positions; L1 is the position of Shoulder Centre captured by said gesture-based camera; T1 is the position of Shoulder Centre collected in calibration procedure; and | | is Absolute operation on one vector.

37. The method according to claim 36 wherein said step of determining a compensation strategy further comprises:

determining three distances values between unaffected wrist joint and the affected upper limb in response to said difference of shoulder centre being below said predetermined threshold;

comparing said three distances values with a predetermined threshold; and

determining limb support in response to said three distances values being less than said predetermined threshold.

10

38. The method according to claim 37 wherein said step of determining three distances values between unaffected (left) wrist joint and the affected upper limb in response to said difference of shoulder centre being below said predetermined threshold comprises:

determining a first distance between left and right wrist of said individual,

determining a second distance between left wrist and right elbow of said individual;

and

determining a third distance between left wrist and right shoulder of said individual.

20