A Virtual System for Balance Control Assessment at Home

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Abstract. Postural stability is often compromised in many pathological states and decreases with age. In clinical practice, an objective tool for balance control at home is fundamental. Recently, virtual tools, based on the use of depth cameras, have been presented. In this paper, a virtual system for balance control assessment is presented and used to implement a virtual task for balance tracking in real time at home. The usability of the tool is assessed through some experimental data collected by 6 healthy elderly people, that used the system and evaluated it through a questionnaire. Results are reported and discussed.

Keywords: Postural balance · Rehabilitation · Virtual reality

1 Introduction

Balance control is the ability to maintaining the body Center Of Mass (COM) within its limits of stability. This capability, fundamental for controlling body movement, decreases with age [1] and could be compromised by many pathologies [2–4]. Both for diagnostic purposes (a timely control of the postural stability reduction could prevent the risk of falls) and for assessing therapeutic progresses an objective and quantitative postural balance assessment at home is needed. Recently, the effectiveness of a new generation of virtual instruments, exercises and practices for rehabilitation have been studied and developed [5–14].

The evolution of the postural sway can be defined statically, if measurements are made while the subject tries to remain still standing, or dynamically, if the measurements are made under the effects of tasks aiming at changing balance conditions (important to assess the maintenance of an unstable equilibrium) [15]. Obviously, systems allowing dynamic measurements are also usable for static studies.

Postural sway could be estimated starting from kinetic or kinematics parameters. The kinetic information include the excursion of the Center of Pressure

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(COP), applied to a support surface, and measured by means of clinical force platforms [16] or low-cost commercial instruments, like for example the Wii Balance [17].

The kinematic data could be used to estimate the spatial position of the Center of Mass and, consequently, its vertical projection on the ground, the Center of Gravity (COG). It could be measured by using wearable inertial sensors [18] or optical motion analysis [19]. In particular, in [19] a low-cost tool for COM/COG assessment, based on a TOF camera has been described.

During a virtual balance task, the COG excursions have been recorded and compared with the movements done by COP, acquired by means of a force platform. Results have shown that this tool was able to assess the sway of the human body also in dynamic conditions. The system had a lower dynamic range than a physical force platform, mainly due to the difference between COG and COP [20]. However, those differences were more evident in the Medio-Lateral (ML) direction of the subject movements than in the Antero-Posterior (AP) direction [19].

This systematic error was produced because the Field Of View (FOV) of the camera was partial. Moreover, to ensure a real-time response, the model of the human body was approximated by a reduced set of spheres over the depth map. In [21,22], a refinement of the system has been proposed to overcome these limitations by using a mirror. In fact, the mirror allowed the focusing of occluded portions of the body and could be used both with a Structured Light (SL) Camera (e.g. Kinect 1) or with a TOF Camera (e.g. Kinect 2). The use of the mirror, instead of an additional depth sensing camera, had two advantages: it was cheap and it avoided multiple-camera synchronization and high-frequency acquisition. The present paper describes a balance tracking software to assess the balance control ability in elderly people at home; the application is integrated with the system [21,22] and tested on a set of 6 healthy elderly people.

The paper is organized as follows: Sect. 2 describes the proposed system, briefly reports the depth map generation process for TOF or SL cameras, summarizes the balance assessment system, and describes the application for the dynamic and real time balance tracking. Section 3 shows and discusses some experimental results regarding the system usability, whereas in Sect. 4 some conclusions are presented.

2 System Design

The proposed system was designed to fit the requirements of three stakeholders: the beneficiary, the therapists, and the caregivers. Potential beneficiaries are, mainly, aged people but also people with balance deficits derived from neurological or musculoskeletal disorder (in the following we use also the term "user" to identify the "beneficiary", though a user of the system could also be a therapist or a caregiver). Regarding the beneficiaries, the system has to be easy to use, presuming that most of them probably are unskilled of computers. In fact, the system must be usable at home without external help. Moreover, the system should elaborate the current balance session and exhibit to the user the outcome of the session itself (in case of positive result, the system should show a positive message to the user whereas in case of negative result, the system should signal a warning). Finally, the system has to be safe, in the sense that it has to be easily set by qualified therapists, according to the users capacities and needs, but it must not be allowed to the users to modify the system setting, in order to avoid dangerous situations (the system could become the cause of falls!). According to the therapist stakeholder, besides the possibility of setting, the system has to store raw data of executed sessions, and to furnish simply usable tools for rapid data retrieving, analysis, and visualization. Referred to the caregivers, the main target is to be informed regarding the regular usage of the system (jumping a planned session could imply a warning situation) and of the results of the monitoring activity (a negative outcome of the current session would imply a warning message).

The system architecture is structured in order to be deployed on up to three different machines. As shown in Fig. 1, four main components can be identified: (a) the depth camera and the mirror, essential for the COG assessment; (b) the installation machine used to calibrate the system, equipped with the software necessary to collect both the RGB and the depth map from the camera and the Matlab environment with the Camera Calibration Toolbox [23]; (c) the server machine, equipped with the driver and the libraries for the communication with the depth map, that hosted both the COG computation module and the web application for the static and the dynamic posturography; (d) the client machine, where only a web browser has to be installed.

2.1 Integration of a Depth Camera with a Mirror

The depth sensing camera can be plugged, by means of an USB connection, both to the server or to the installation machine, depending on the state in which the system is (calibration state or balance tool execution state). As demonstrated in [19], the camera is used in conjunction with a mirror in order to improve the COG assessment accuracy, by retrieving information about the hidden surface of the user body.

TOF sensors are composed by an emitter and a sensor matrix that work at near infrared (NIR) light frequencies. As shown in Fig. 2a, by enlightening the scene with a light (by means of the emitter E), modulated in amplitude by a *sine* of frequency f_{mod}, and measuring the phase shift (φ_{shift}) between the emitted and the reflected signal (captured by the sensor S), it is possible to compute the distance of an object O from the matrix plane and the depth map of the scene [24]. Then, being note the horizontal and the vertical fields of view of the camera, it is possible to compute the spatial coordinates of a point O = (x_O, y_O, z_O), referred to a three-dimensional Cartesian coordinates system, typically centered on the middle of the camera sensor.

Figure 2b, shows that the placement of a mirror in the scene allows the indirect observation of an object, through its reflection: the light, reflected by the mirror, hits the object O and it is detected by the sensor S as if there is a

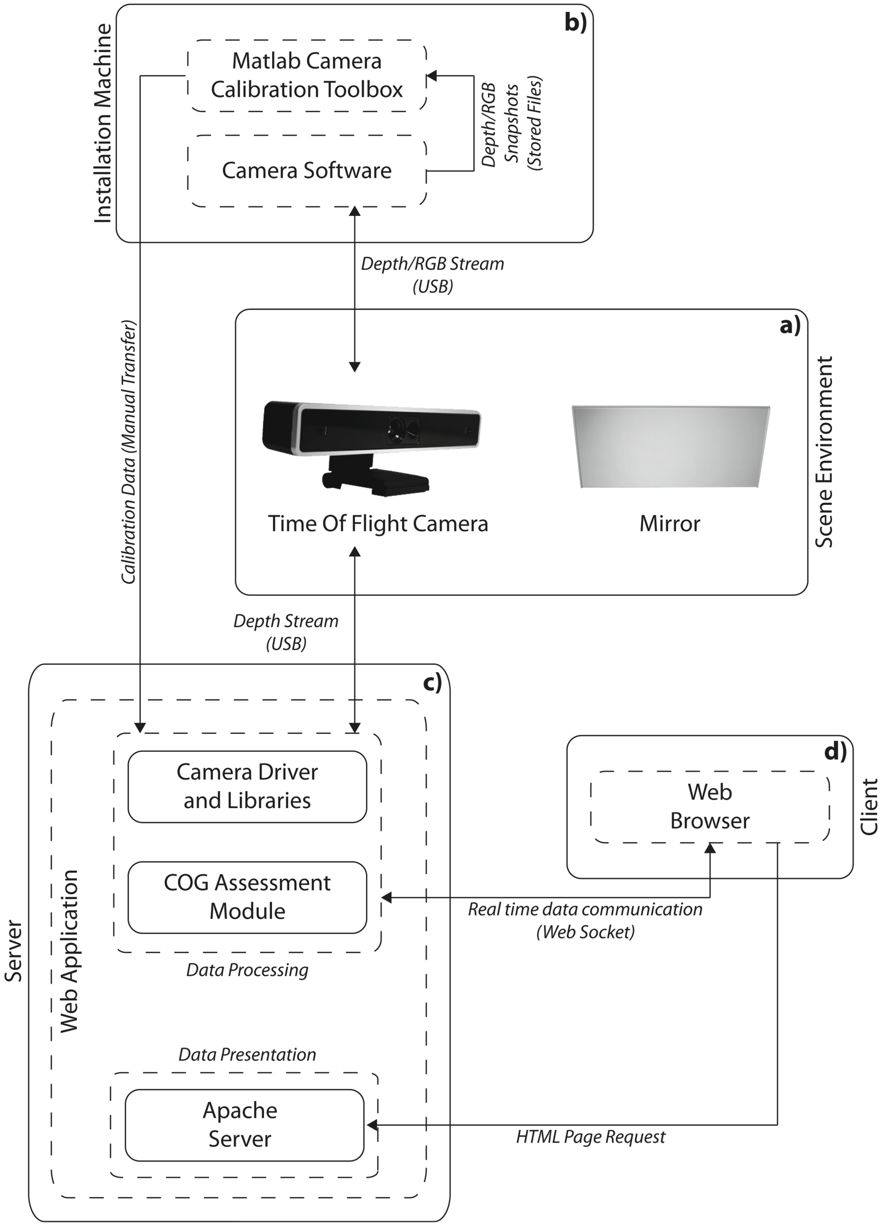

Fig. 1. Architecture diagram of the system, composed by four main components: (a) the TOF camera and the mirror, (b) the installation machine (c) the server machine, (d) the client machine.

virtual space behind the mirror plane that contains the reflection of the object, the sensor and the emitter E. The reflected virtual object VO is like the real object O, seen by a virtual sensor VS, after a horizontal image flip. If the equation of the plane containing the mirror surface with respect to the coordinate system is known, it is possible to estimate the position of the real object using the information from the reflected one [21,22].

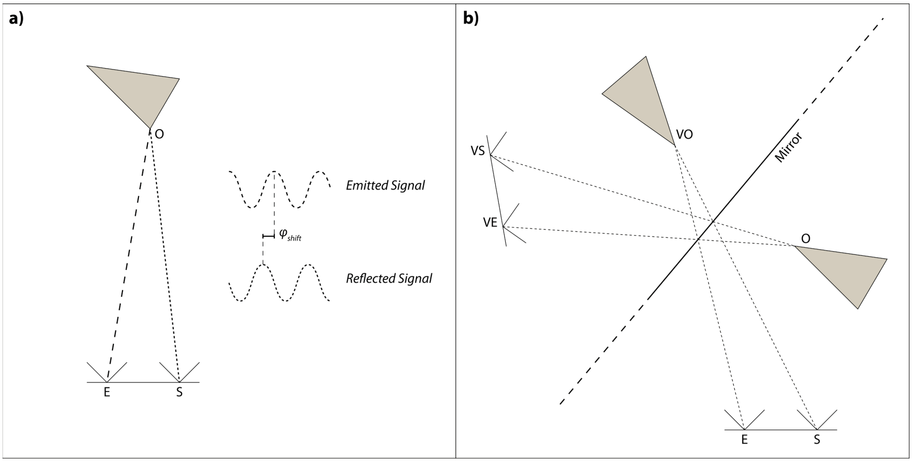

Fig. 2. a) Time of flight (TOF) camera operating principle: the emitter E enlightens the object O with a modulated light while the sensor S captures the reflected signal, allowing to compute the phaseshift between emitted and reflected signals. (b) the virtual space created by placing a mirror in the scene contains virtual versions of the emitter (VE), the sensor (VS) and the object (VO).

2.2 The Installation Machine

The installation machine function is to allow a technician to set up the COG acquisition system. It is designed to perform the calibration described in [22], that is to find the equation of the plane the contains the mirror, with respect to the reference coordinates system. Indeed, reversing the above argument, it is possible to derive the equation of the mirror plane, starting from the position of a point and its reflection. In the proposed system, due to the TOF sensor low resolution, it is preferred to calculate the position of the depth sensor (the origin of the coordinates system) and its reflection. The chosen approach consists in two main phases: first, the position of RGB sensor with respect to the TOF sensor is found, by using a set of images of a special chessboard formed by alternating opaque and reflective squares visible from both sensors; second, a set of images of a chessboard, seen both directly and through its reflection, is used to calculate the reciprocal positions of the two RGB sensors (the real and the virtual one seen through the mirror). As shown in Fig. 3, the same image is used to represent the views of the object from both the cameras, after a horizontal flip. These information allows to compute the reciprocal position of the two TOF sensors and the plane equation. In this phase, the coordinates of a pixel in the depth map, belonging to the ground, are calculated in order to store the height H of the camera from the floor. In the proposed version of the system, the calibration process is performed by using the Camera Calibration Toolbox [23], and produces a binary output file containing the plane coefficients value and the camera distance from the floor H, manually transferred to the server machine. In future developments, this step will be implemented in proprietary software tool, that will simplify operations needed during the process, by means of a wizard, allowing the therapist or the caregiver to set up the system. For this reason the technician is not identified as stakeholder.

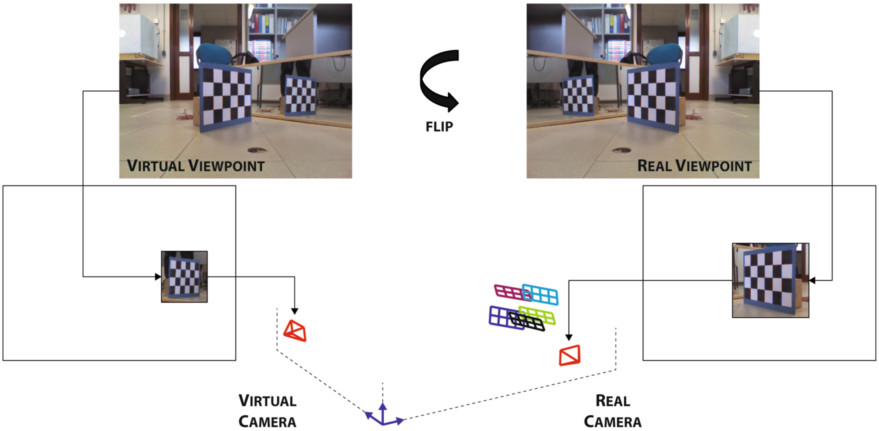

Fig. 3. The couple of images used for the calibration between the real and the virtual RGB cameras: one is obtained as the horizontal flip of the other. The result of the calibration test, indicating the mutual position of real camera with respect to the virtual one, is also shown (below).

2.3 The Server Machine

The server machine hosts the web application that executes two main modules, data processing tool and data presentation tool. The first manages the communication with the TOF camera and is equipped with the implementation of the COG assessment algorithm described in [22]. Two phases are required, for each frame, in order to obtain the COG: the 3D positioning and the COG evaluation.

The 3D positioning aims at computing, for each frame, the spatial coordinates of the body surface by using the pixels allowing both to the direct foreground and to the reflected one. First, each point of the foreground is determined in the 3D coordinates system (direct and reflected images are managed in the same way). Second, it is marked as “real”, if belonging to the same half-space of the system origin, "virtual" elsewhere (this operation is simplified by reserving a region of scene to the mirror). Finally, the reflection with respect to the mirror plane is applied to each virtual pixel.

For the COG evaluation a weight-based approach is used in order to normalize the pixel contribution to the COG evaluation, proportionally to the body surface covered by it (a closer pixel would have a lower contribution with respect to a farther one). Since the surface covered by a pixel increases like the square of the distance, for each pixel i belonging to the foreground F, the considered weight is:

$$w_i = \frac{d_i^2}{\sum_{j \in F} d_j^2}. \tag{1}$$

where d_i is the original (before the reflection operated by the 3D positioning) pixel distance from the camera. After normalization, the COM coordinates are computed as follows:

$$COM = \left(\sum_{j \in F} w_j x_j, \sum_{j \in F} w_j y_j, \sum_{j \in F} w_j z_j \right). \tag{2}$$

while the COG coordinates, corresponding to the vertical projection of the COM on the ground, are calculated as:

$$COG = \left(\sum_{j \in F} w_j x_j, -H, \sum_{j \in F} w_j z_j \right). \tag{3}$$

The data processing module is developed in C++ and includes a websocket server able to manage, through a real time communication, a large numbers of messages exchanged from and to the client. It must synchronize the information processed by the COG algorithm and consumed (and presented) by the client itself. WebSockets protocol [25] has been selected for the proposed system because it provides a consistent latency reduction and avoids unnecessary network traffic, if compared to polling and long-polling solutions that are used to simulate a full-duplex connection by maintaining two connections. Thus the WebSockets represent a standard for bi-directional real time communication/applications [26].

Data presentation module exploits the features of the installed Apache Server [27] and is used to deploy the graphic interface pages and to handle the http requests from the web-browser.

The above design, following the classic client-server architecture, allows to deploy the modules for data processing on the server machine, thus limiting the role of the client to simply host a web browser. This choice has been successfully used also in the interface design of a communication tool for impaired people [28].

Figure 4 shows the two possible execution scenarios of the system: the first (Fig. 4(a)) is designed for static posturography, the second (Fig. 4(b)) is used to execute a combined static/dynamic posturography chain.

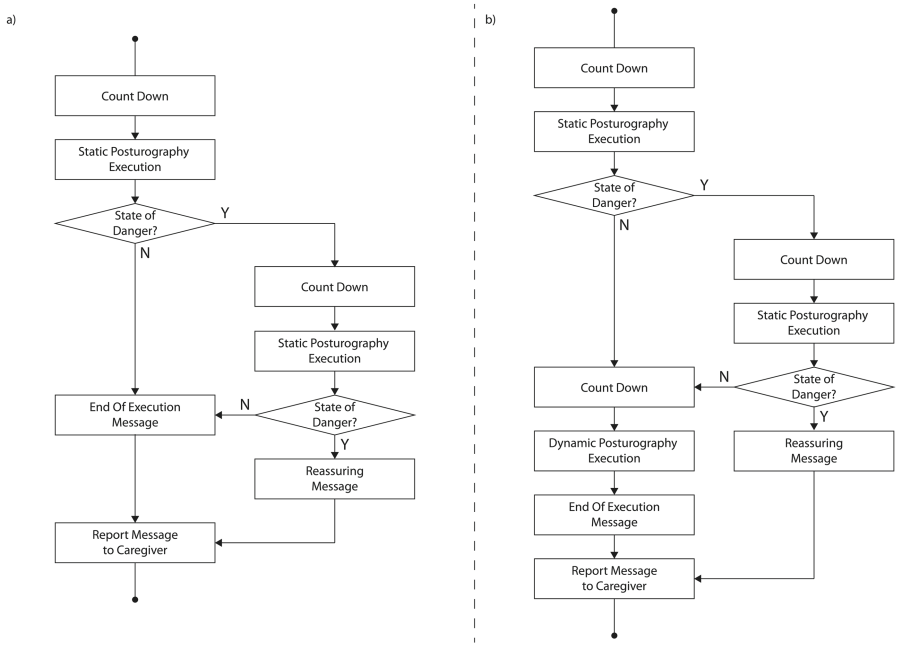

Fig. 4. Block Diagram of the two possible COG control scenarios: (a) while maintaining a static position; (b) by using a multiple task consisting both in maintaining a static position and tracking a moving target (for safety issues, the tracking task is allowed only if the static position maintenance has a positive outcome).

In both scenarios the tool is used as a control instrument, in order to periodically check the balance control of the subject and notify the caregiver of daily executions and progresses and, above all, of potential dangerous balance states recorded by the system. The balance check is performed through the execution of up to two static posturography sessions. If both of them result in a warning, by exceeding the displacement limit either for AP or ML swaying, the system displays a reassuring message that is intended to calm down the subject and to make him sit down, without worry him: "Please wait until computation is complete. Take a seat and rest for a minute". At the end of the scenarios, a system call is executed, in order to report to the caregiver about the state of the subject. The effects of the call can be defined by modifying the type and the content of the file indexed in the setting (it could be, for example, a batch file or an executable). Thus, several strategies could be used to report, like sending an email, doing a http request or exploiting an SMS provider.

Static posturography is designed to assess the ability of the user to maintain fixed his COG. The user has to keep is arms along the body and his feet joined, staying as still as possible.

In this case the user interface contains just the representation of the user COG position (drawn as a circle) and its movement on the horizontal plane

(Fig. 5(a)). Dynamic posturography aims at evaluating the ability of the user to follow a specific trajectory with his COG, starting from the same position assumed during the static posturography and just moving his ankles.

The target trajectories are represented by a gun sight moving with random oscillations around the center of the scene while the user COG is drawn as a circle (Fig. 5(b)).

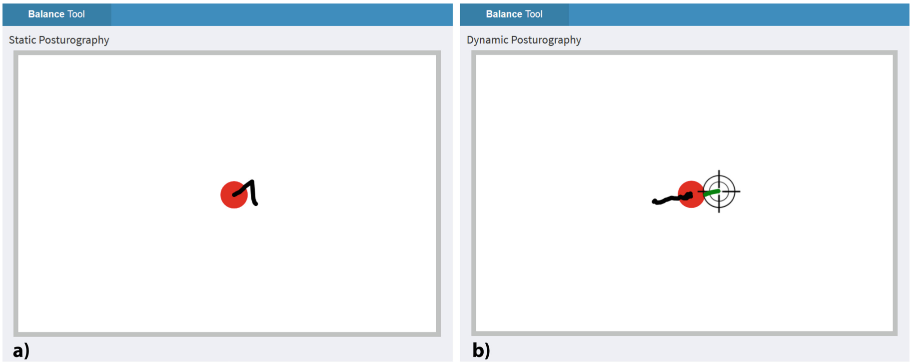

Fig. 5. Screenshots of the client application (in the web browser). Left panel (a) reports the static posturography window, containing the representation of the user COG position (red circle) and its trajectory on the horizontal plane (black stroke). Right panel (b) represents the dynamic posturography window: the target is represented by a gun sight moving, with a pre-determined trajectory (the last two seconds of the followed path is indicated by a green stroke), around the center of the scene and the user COG is drawn as a red circle with the last 2 s of its trajectory (black stroke). (Color figure online)

The whole system is designed to require the minimum possible amount of operations that the user has to perform to use the system and, at the same time, to avoid the possibility of wrong setting that an unskilled user could produce. A text file stored on the server machine defines the values of parameters used in the application: the scenario that has to be executed (COG control both maintaining a static position or tracking a moving target), the task duration (both for static and dynamic tasks), the delay between the execution of the application and the beginning of the task, the AP or the ML values of displacement that, if exceeded during the static posturography, has to be considered dangerous and, finally, the path of the file that has to be executed in case of a balance warning situation.

Data recorded during the executions are stored in the server machine in order to give to the therapist the possibility of analyzing and comparing them in future.

3 System Evaluation

The proposed system has been evaluated, in terms of user usability, by performing a set of test sessions.

The experimental settings was composed of a TOF camera [29], located at 3.5 m from the expected subject location and 1.45 m from the floor, and a squared mirror (1.5 m sided), positioned with its center at 4.5 m from the camera and 2.35 m from the floor. The mirror was inclined by 50° with respect to the vertical position. The machines acting as server, client and installation coincided to the same computer, an Intel i7 (2.3 GHz) with 4 GB of RAM and Windows 7 (64bit). The web browser that played the client role has been executed in full-screen option and projected from the ceil on the floor, just in front of the user position, in order to increase the feeling of augmented reality for the user. The executed scenario was composed by 90 s long static and dynamic tasks (Fig. 4(b) and settings included a delay before each posturography test of 15 s and a 5 cm displacement warning value, both for AP and ML directions.

Experimental data has been collected by 6 healthy voluntary subjects, 3 women and 3 men, average age of 60.7 years (±3.2 years). The subjects had scarce or absent ability of using computers. Each participant has been summoned, the day before the test, for a brief, individual meeting, regarding the correct use of the system.

Experimental test required a list of operation that had to be performed by the subjects: (a) running the server application; (b) opening the browser and connecting to the application URL (this operation is facilitated by a shortcut icon on the desktop); (c) executing the combined sequence of task; (d) closing the browser and the server.

All the subjects have achieved to perform the dynamic task passing through the static check only once. After the session each participant has been requested to fill the SUS questionnaire [30], in order to evaluate the usability of the system. The SUS questionnaire is composed by 10 item that have to be scored in the range from 1 to 5 (meaning from "strongly disagreement" to "strongly agreement"): five items are related with a positive usability meaning (e.g. "I felt very confident using the system"), while the remaining are negative statements (e.g. "I found the system unnecessarily complex"). The final score S, ranging from 0 to 100, is computed as follows:

$$S = \left(\sum_{j \in P} (V_j - 1) + \sum_{j \in N} (5 - V_j) \right) * 2.5. \tag{4}$$

Where P and N are the set of positive and negative items respectively, and V_i is the value assigned to the statement i.

The system has been scored with 71.7 as average usability value, corresponding with quite positive overall opinion. Figure 6 summarizes the individual questionnaire results: 5 subjects have valuated the system usability with a score of 65 or above while one (Subject #5) has found the system very difficult to be used.

Since the subject had almost never experienced the use of a personal computer, most of the difficulties could be attributed to the interaction with the operating system more than with the proposed system. Indeed, both during the training session and the test session, the subject has been observed to have problem with basic operations like double-clicking on an icon or closing a window. The other subjects have considered easy or friendly the interaction with the proposed system and, though the questionnaire was strictly related to usability, some of them have pointed out that they have found funny the dynamic version of the system.

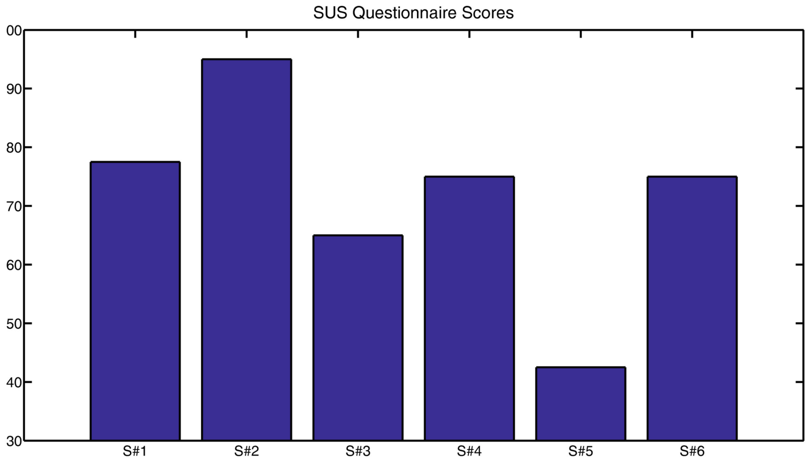

Fig. 6. Chart of the SUS questionnaire scores over the subjects. Scores axis is shown cut (from 30 to 100) for visualization purposes.

Figure 7 reports, as an example, the COG movements recorded during the Subject #1 dynamic session. The figure also shows the trajectory of the moving target (in particular, in the first and the second graphs the user trajectories are shown with continuous lines, while the target movements are represented by dotted lines). As it is possible to see from the plots, the user COG follows trajectories that includes higher frequencies components with respect to those drawn by the target (due to trembling movements). The COG trajectory also presents an obvious temporal delay (the user had to adapt his actions to the target) and greater oscillations amplitudes, because the user response to the target changes of direction was not immediate, leading him to overtake it.

Data reported are an example of the information that could be analyzed and elaborated by the therapist, by taking into account the COG movements and, in case of dynamic tasks, the position of the target.

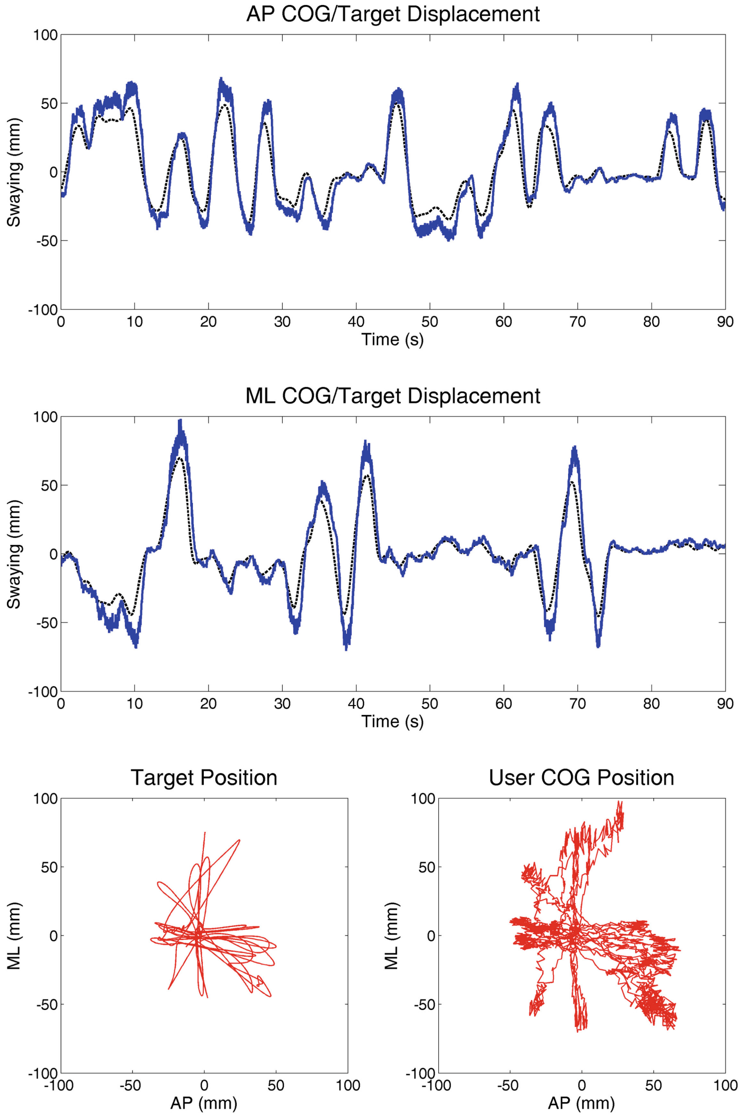

Fig. 7. Representation of the COG movements (AP and ML components) recorded and visualized by the system during a dynamic session the Subject #1. In particular, the continuous lines represent the target trajectories and the dotted lines represent the COG trajectories of the analyzed subject. In the last row the figure show the trajectories represented on the plane.

4 Conclusion

An objective and quantitative postural balance assessment at home is needed both for diagnostic purposes and for assessing therapeutic progresses. In this paper a virtual system for postural stability control system is described and tested, regarding its usability for the beneficiary users, on 6 elderly healthy people. The users were instructed to use the system and were invited to perform the combined static/dynamic balance control session. Nobody has been excluded by the dynamic session of the task, meaning that all the subjects have passed the stage of static equilibrium. After the use of the system, the subjects have been asked to fill the SUS questionnaire. Though all the users were unskilled with computers, most of them (except one) have found the system very easy to use. Future work will be devoted in testing the functions of the system to be used by therapists and to test the proposed system directly on patients under the supervision of expert therapists.

References

1. Bogle Thorbahn, L.D., Newton, R.A.: Use of the Berg Balance Test to predict falls in elderly persons. Phys. Ther. **76**(6), 576–583 (1996)
2. Colnat-Coulbois, S., Gauchard, G.C., Maillard, L., Barroche, G., Vespignani, H., Auque, J., Perrin, P.P.: Bilateral subthalamic nucleus stimulation improves balance control in Parkinson's disease. J. Neurol. Neurosurg. Psychiatry. **76**(6), 780–787 (2005)
3. Mancini, M., Horak, F.B.: The relevance of clinical balance assessment tools to differentiate balance deficits. Eur. J. Phys. Rehabil. Med. **46**(2), 239–248 (2010)
4. Kato-Narita, E.M., Nitrini, R., Radanovic, M.: Assessment of balance in mild and moderate stages of Alzheimer's disease: implications on falls and functional capacity. Arq. Neuro-Psiquiatr. **69**(2), 202–207 (2011)
5. Lange, B., Chang, C.Y., Suma, E., Newman, B., Rizzo, A.S., Bolas, M.: Development and evaluation of low cost game-based balance rehabilitation tool using the Microsoft Kinect sensor. In: 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, pp. 1831–1834. IEEE Press, Boston (2011)
6. Carrieri, M., Petracca, A., Lancia, S., Basso Moro, S., Brigadoi, S., Spezialetti, M., Ferrari, M., Placidi, G., Quaresima, V.: Prefrontal cortex activation upon a demanding virtual hand-controlled task: a new frontier for neuroergonomics. Front. Hum. Neurosci. **10**, 53 (2016)
7. Basso Moro, S., Bisconti, S., Muthalib, M., Spezialetti, M., Cutini, S., Ferrari, M., Placidi, G., Quaresima, V.: A semi-immersive virtual reality incremental swing balance task activates prefrontal cortex: a functional near-infrared spectroscopy study. NeuroImage **85**(1), 451–460 (2014)
8. Avola, D., Spezialetti, M., Placidi, G.: Design of an efficient framework for fast prototyping of customized human-computer interfaces and virtual environments for rehabilitation. Comput. Methods Programs Biomed. **110**(3), 490–502 (2013)
9. Petracca, A., Carrieri, M., Avola, D., Basso Moro, S., Brigadoi, S., Lancia, S., Spezialetti, M., Ferrari, M., Quaresima, V., Placidi, G.: A virtual ball task driven by forearm movements for neuro-rehabilitation. 2015 International Conference on Virtual Rehabilitation (ICVR), pp. 162–163. IEEE Press, Valencia (2015)

10. Lloréns, R., Noé, E., Naranjo, V., Borrego, A., Latorre, J., Alcañiz, M.: Tracking systems for virtual rehabilitation: objective performance vs subjective experience. A practical scenario. Sensors **15**, 6586–6606 (2015)
11. Placidi, G.: A smart virtual glove for the hand telerehabilitation. Comput. Biol. Med. **37**(8), 1100–1107 (2007)
12. Franchi, D., Maurizi, A., Placidi, G.: Characterization of a simmechanics model for a virtual glove rehabilitation system. In: Barneva, R.P., Brimkov, V.E., Hauptman, H.A., Natal Jorge, R.M., Tavares, J.M.R.S. (eds.) CompIMAGE 2010. LNCS, vol. 6026, pp. 141–150. Springer, Heidelberg (2010). doi:10.1007/978-3-642-12712-0_13
13. Placidi, G., Avola, D., Iacoviello, D., Cinque, L.: Overall design and implementation of the virtual glove. Comput. Biol. Med. **43**(11), 1927–1940 (2013)
14. Basso Moro, S., Carrieri, M., Avola, D., Brigadoi, S., Lancia, S., Petracca, A., Spezialetti, M., Ferrari, M., Placidi, G., Quaresima, V.: A novel semi-immersive virtual reality visuo-motor task activates ventrolateral prefrontal cortex: a functional near-infrared spectroscopy study. J. Neural Eng. **13**, 3 (2016)
15. Visser, J., Carpenter, M., van der Kooij, H., Bloem, B.: The clinical utility of posturography. Clin. Neurophysiol. **119**(11), 2424–2436 (2008)
16. Prosperini, L., Pozzilli, C.: The clinical relevance of force platform measures in multiple sclerosis: a review. Multiple Sclerosis International, pp. 1–9 (2013)
17. Wii Balance Board. http://wiifit.com/what-is-wii-fit-plus/#balance-board
18. Bonato, P.: J. NeuroEng. Rehabil. **2**, 2 (2005)
19. Placidi, G., Avola, D., Ferrari, M., Iacoviello, D., Petracca, A., Quaresima, V., Spezialetti, M.: A low-cost real time virtual system for postural stability assessment at home. Comput. Methods Programs Biomed. **117**(2), 322–333 (2014)
20. Zatsiorsky, V., King, D.: An algorithm for determining gravity line location from posturographic recordings. J. Biomech. **31**(2), 161–164 (1997)
21. Placidi, G., Petracca, A., Pagnani, N., Spezialetti, M., Iacoviello, D.: A virtual system for postural stability assessment based on a TOF camera and a mirror. In: Proceedings of the 3rd 2015 Workshop on ICTs for Improving Patients Rehabilitation Research Techniques, pp. 77–80. ACM, New York (2015)
22. Spezialetti, M., Iacoviello, D., Pagnani, N., Petracca, A., Placidi, G.: Mirrors and depth camera to emulate a multiple sensors environment for postural stability assessment. In: Methods of Information in Medicine (2016, submitted)
23. Camera Calibration Toolbox for Matlab. http://www.vision.caltech.edu/bouguetj/calib_doc/
24. Hansard, M., Lee, S., Choi, O., Horaud, R.P.: Time-of-Flight Cameras: Principles, Methods and Applications. Springer, London (2012). doi:10.1007/978-1-4471-4658-2
25. RFC 6455 - The WebSocket protocol. https://tools.ietf.org/html/rfc6455
26. Pimentel, V., Nickerson, B.: Communicating and displaying real-time data with websocket. IEEE Internet Comput. **16**, 45–53 (2012)
27. The Apache HTTP Server Project. https://httpd.apache.org/
28. Placidi, G., Petracca, A., Spezialetti, M., Iacoviello, D.: A modular framework for EEG web based binary brain computer interfaces to recover communication abilities in impaired people. J. Med. Syst. **40**, 34 (2015)
29. W20130527 SK DS311 Datasheet Recto V3.0 vectorized - SoftKinetics; c2007–2015. http://www.softkinetic.com/
30. Brooke, J.: SUS-A quick and dirty usability scale. Usability Eval. Ind. **189**(194), 4–7 (1996)

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