Image-Based Mobility Assessment in Elderly People from Low-Cost Systems of Cameras: A Skeletal Dataset for Experimental Evaluations

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Abstract. In recent years, the scientific community has found increasing interest in technological systems for the evaluation of the mobility performance of the elderly population. The reduced quantity of dataset for gait and balance analysis of elderly people is a serious issue in studying the link between cognitive impairment and motor dysfunction, particularly in people suffering from neurodegenerative diseases. In this context, this work aims to provide a dataset with skeletal information of people aged 60 years and older, while they perform well-established tests for stability assessment. 27 healthy people and 20 patients affected by neurodegenerative diseases, housed at two different nursing institutes, have been selected for the stability analysis. Subjects have been observed and evaluated by clinical therapists while executing three motion tests, namely balance, sit-to-stand and walking. The stability postural and gait control of each subject has been analyzed using a video-based system, made of three low-cost cameras, without the need for wearable and invasive sensors. The dataset provided in this work contains the skeletal information and highly-discriminant features of the balance, sit-to-stand and walking tests performed by each subject. To evaluate the efficiency of the balance dataset, the estimated risk of fall of the subjects has been processed considering the extracted features, and compared with the expected one. Final results have proven a good estimation of the risk of fall of the people under analysis, underlining the effectiveness of the dataset.

Keywords: Skeletal dataset · Neurodegenerative diseases · Low-cost cameras · OpenPose

1 Introduction

It has been shown that there is a strict link between cognitive impairment and motor dysfunction such as deficits in gait and balance [6,9]. Furthermore, func-

L. A. Grieco et al. (Eds.): ADHOC-NOW 2020, LNCS 12338, pp. 125–130, 2020.
https://doi.org/10.1007/978-3-030-61746-2_10

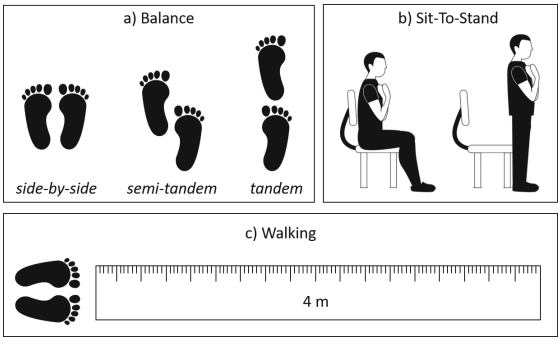

Fig. 1. SPPB tests: a) Balance test, which is composed of three exercises where the patient has to stand with the feet in side-by-side, then in semi-tandem and finally tandem positions; b) Sit-To-Stand test, which consists in sitting and standing up 5 times while keeping the arms crossed on the chest; c) Walking test, which consists in the patient covering a path of 4 m.

tional assessment measure protocols can help to qualify gait and posture of the patients. In this scenario, the Short Physical Performance Battery (SPPB) represents a well-established means to assess physical performance status and evaluate functional capabilities [3], to monitor and prevent the risk of falls. Such functional assessment measure is composed of three tests to assess lower body function, namely Balance Test (BT), Sit-To-Stand Test (STST) and Walking Test (WT), which instructions are represented in Fig. 1.

The risk of fall is qualitatively evaluated by expert clinical personnel with respect to the execution of the SPPB tests, in agreement with the medical protocols. Despite the high professional competence of the operators, the need for developing innovative technological systems is of great interest, since human-based assessment can be susceptible to drifts and biases. For this purpose, the need for datasets containing physical performance status information is becoming an issue of increasing interest, as the development of new technological systems that can support clinical personnel strictly depends on both the quality and quantity of available data.

In literature, various datasets related to the evaluation of the motion skills of elderly people are presented [1,5,7], yet none of them gives skeletal information specifically to the SPPB protocol. Most of the datasets outlined in literature provide information only regarding the static analysis of the patient, without releasing information about the dynamic aspect, which is fundamental in evaluating the risk of falls. Moreover, even when the patient's skeleton is analyzed, the dataset often concerns only a singular type of exercise, thus producing a non-heterogeneous amount of data.

This work provide a complete dataset of age, sex and skeletal information of people aged 60 years and older, while they perform all the three tests included in the SPPB protocol. A complete vision-based system, made of three low-cost cameras, has been developed for accurately measuring stability postural control,

Table 1. Classification method for each test. Each exercise is assessed based on its duration.

Test	0	1	2	3	4
Balance	*Side-by-side*	0–9 s *semi-tandem*	0–2 s *tandem*	3–9 s *tandem*	10 s *tandem*
Sit-To-Stand	*Incapable*	>7.5 s	7.4–5.4 s	5.3–4.1 s	<4.1 s
Walking	*Incapable*	>16.6 s	16.6–13.7 s	13.6–11.2 s	<11.2 s

without the need for wearable and invasive sensors. The exercise videos, grabbed from two nursing institutes, have been normalized and synchronized to extract the most significant features from the skeletons, which carry information about balance, gait, and strength, to properly evaluate the risk of falls. Such features, along with sex, age, and the skeletal information of the patient itself, have been added to the dataset. The reliability of the dataset has been tested using the features extracted in the BT as input of a classifier [8]. Final results have proven a good estimation of the risk of fall of people under analysis.

The paper is structured as follows. Section 2 defines the tests included in the SPPB protocol. In Sect. 3 the developed methodology is defined, along with the video pre-processing and the feature extraction for the provided dataset. Section 4 draws the evaluation of the dataset, highlighting its efficiency. Finally, the conclusions are presented in Sect. 5.

2 Tests Definition

The proposed paper aims to establish the risk of fall of elderly people and patients affected by neurodegenerative diseases, through the analysis of the tests included in the SPPB. Several patients, housed at the two nursing institutes of the study, have been selected for the postural and stability analysis. Each patient has been instructed to perform first the BT, then the STST, and finally the WT. For each test, a specialized therapist observes the patients and measures their time execution using a stopwatch. Such tests are then evaluated following an appropriate score system, shown in Table 1.

In the following, the SPPB tests are defined:

- **Balance Test:** The test of standing balance includes side-by-side, semi-tandem and tandem positions. The patient is instructed to maintain each position for 10 s, measured by a clinical therapist. If a patient fails to complete the test within ten seconds, the elapsed time is measured anyway.
- **Sit-To-Stand Test:** The STS test consists of sitting and rising from a chair placed against the wall for safety purposes. The patient is asked to fold her/his arms across her/his chest, and to stand up and sit down from the chair 5 times. A clinical therapist times the exercise starting from the initial sitting position to the final standing position.

– **Walking Test:** During the walking test, the patient is instructed to follow a path of 4 m with no obstructions. A clinical therapist is in charge of timing the exercise.

3 Methodology

3.1 Camera Setup and Video Pre-processing

The whole setup consists of three low-cost cameras, namely the HIKVision [4], usually used for video-surveillance. The three cameras have been installed in fixed position, along the sides of a volume of interest. As stated previously, two setups have been designed and installed in two nursing homes, under different condition of lighting, acquiring 720 × 480 resolution videos.

As the output videos are not suitable for image processing in their raw form, a pre-processing phase is mandatory to prepare the videos to the following feature extraction procedure. In detail, the pre-processing stage is a sequence of selection and conversion algorithms, namely:

– **Frame per second (FPS) conversion:** As the videos from the three cameras have variable framerates, the lowest framerate among the three videos has been selected, projecting the time axes on a common reference, sampled with a unique framerate to achieve uniformity.
– **Video shifting:** A start signal, given the clinical therapists with a remote control, triggers the three video acquisitions, which however start with non-negligible relative delays. To overcome such issue, the early-started videos are shifted of a number of frames equal to the relative delays.
– **Video trimming:** As most of the videos are long streams, the input streams are trimmed in exercise-related sub-videos.
– **Video Calibration:** As the videos suffer from image distortion, the extrinsic parameters have been extracted from the cameras of both setups to properly calibrate them.

3.2 Features Extraction

The complete knowledge of the position in space, or equivalently in the image plane, of the skeletal joints of the patients is enough to infer postural information. For this reason, the feature extraction process starts with the detection of the skeleton of the patients under analysis.

Skeleton detection is performed by means of the OpenPose library [2], which gives a real-time multi-person 2D pose estimation, aiming to represent both position and orientation of human limbs. For this work, the COCO training model has been implemented. It allows the identification of 18 skeletal joints from each person.

Different features have been chosen depending on the type of exercise, aiming to extract the most relevant information according to the test under analysis. As a matter of fact, each test provides different, yet relevant information regarding

Fig. 2. SPPB tests performed by different patients. Namely, a) Balance Test, b) Sit-To-Stand Test, and c) Walking Test.

the posture and stability of the patient. Therefore, it reveals to be fundamental to properly select the highly-discriminant features with respect to each test, in order to suitably gather an amount of information about the patient as heterogeneous as possible.

4 Dataset Evaluation

The proposed paper has been developed to provide sex, age, skeleton information and highly-discriminant features of patients performing SPPB tests. 20 patients suffering from a neurodegenerative disease and 27 healthy people perform the tests.

As a first step, all the acquired videos of the exercises performed by the patients have been studied, to evaluate their validity. Then, the preprocessing phase has been carried out to prepare the videos for the skeleton and features extraction, via the application of the OpenPose library. Finally, the dataset is completed with a vector of evaluation scores given by clinical therapists for each test.

Examples of patients performing BT, STST, and WT are shown in Fig. 2. To properly evaluate the efficiency of the dataset[1], the information grabbed from patients performing BTs are considered. The highly-discriminant features extracted from the skeletons are used to feed a decision tree classifier, which has been trained to label patients into 5 classes of increasing risk of falls, shown in Table 1. The final score given by clinical therapists has been compared to estimated one [8]. The good accuracy of the system (equal to 79.1%) shows the effectiveness of the provided dataset.

5 Conclusions

In this paper, a complete dataset composed of sex, age, skeletal information and relevant features of elderly people performing SPPB protocol has been presented. Subjects have been grabbed by a system of three low-cost surveillance cameras. Then, proper video processing techniques have been used to highlight

[1] The dataset will be shortly uploaded on the website: http://cms.stiima.cnr.it/isp/.

the skeletal joints of the subjects and to extract highly-discriminant features. It has been proved the high efficiency of the proposed dataset in the assessment of the patient's stability and posture skills, and their consequent risk of fall.

In the future, further semantic analysis of the videos will be investigated, to analyze more relevant features to be extracted from the skeletons, and to assess the progress of the neurodegenerative disease of patients observed during long periods.

Acknowledgement. The authors thank Michele Attolico and Giuseppe Bono for their technical and administrative support.

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