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Optimization of the Static Posture Evaluation Process Through Digital Processing of Photographic Images

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Abstract— **Traditional methods of posture evaluation carried out by physical therapists manually measure or test the alignments of body segments, investing a long time for its development and adding an error percentage related to the level of professional expertise. The present study uses a system of two dimensions photogrammetry to investigate its applicability on measurement of posture parameters and the variation of the measurements using different photographic cameras locate at different distances from the subject. The "marker automatic measurement" system (LAM) filters and segments body markers on photographic images. Data were collected using a semi-professional, a mid-range cellphone and a sports camera. Tests were recorded by placing the camera at 2.50, 2.00 and 1.80 meters from the subject, and the lens at a height of 1.10, 1.00 and 0.97 meters with an illuminance of 29.92 lux. Subsequently, 30 volunteers participated in the postural tests. The Measurements were made on frontal, anterior and posterior planes as well as sagittal plane. The maximum absolute error on the measuring of distances was 0.64 cm. On angles related to the horizontal was 0.70 degrees and for angles concerning the vertical was 0.76 degrees.**

Clinical Relevance—**By utilizing LAM system all three views were evaluated in less than a minute without counting the time for putting on the markers. The results obtained suggest that the system presents trustworthy results, which reduce considerably the time of carrying out posture evaluations where results are measurable, repeatable and away from the evaluator's subjectivity.**

I. INTRODUCTION

Human body posture has been studied for centuries by artists, as well as scientists, anthropologists, sociologists, physicians, psychologists, physical therapists, orthopedists, ophthalmologist, and nowadays by modern sciences like ergonomics and biomechanics. The study of human posture is relatively new regarding other areas of medical science and it has gained substantial importance and impact during the last years, especially in the area of physical therapy despite the fact that posture evaluation is still an inaccurate science [1]. Static posture has been defined as the alignment of body segments in a determined moment [2]. A posture is considered ideal when body segments are aligned in such a way that a minimum muscle effort is required to keep vertical stability.

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For kinesiology, the posture shows anti-gravitational muscle resistance, the capability of the musculoskeletal system to adjust, in a homeostatic manner, to physical and environmental factors providing clues about relations between structure and physical function.

Alterations of posture alignment may affect all age ranges and are related to several disorders such as: pain syndrome, localized or general musculoskeletal disease [3], respiratory dysfunction [4], elderly falling risks [5] as well as attention deficit disorder in pupils and injure increase in sports athletes [6]. Posture evaluation provides data which may help to improve productive and academic performance [7], diminish of back and musculoskeletal pain, better performance of athletes [8], which is why posture re-alignment is a goal frequently pursued by physicians, dentists, physical therapists [9], companies and industries. In several countries around the world, a posture evaluation is considered as one of the standardized examinations before enrolling any kind of institution. Where posture deviations are related to factors such as height, weight, age, sex, health status and muscular conditioning [8].

Concerning the clinic practice, evaluations of posture are a daily part of physical examination [10]. Posture evaluations are usually subjective, if made through traditional observational methods, since abnormalities are visually checked. This form of qualitative evaluation has a low sensibility as well as low trustworthiness [1], [11]. It depends, to a large extent, on past experiences and interpretations given by the observer's expertise. Consequently, standardized and valid instruments are required in order to carry out more systematic and accurate evaluations, which should increase reliability between evaluators. Many companies and research groups have developed posture evaluation software that usually consists of digital markers for photographic images or the usage of anthropometric tools to evaluate posture [12], [13].

Despite the fact that the study of posture by means of image digital processing is relatively new, it has become an area of big interest for many researchers. One of the main reasons is the possibility to apply new electronic and communicational technologies in order to make posture evaluations that may offer quantifiable data, reproducible almost in an instant way. Currently, among the most used methods to evaluate posture we have:

Visual observation method: this method is the most common in the clinic practice to make evaluations of posture. This type of qualitative evaluation has a low sensibility as well as low reliability since it largely depends on their every experiences and subjective interpretations. Among these

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methods we can mention the plumb line method, the usage of goniometer, the use of a spinal analysis machine and the use of the flexible ruler to measure spinal curving [13], [14].

Radiographic method: it is a recent method considered as a “gold standard”. The posture analysis is made through patient’s radiographies. Even though it is an accurate and exact, it is quite costly and it may affect the subject health [11].

Photogrammetric method: frontal and/or sagittal planes subject’s photographs are taken and spatial relations between reality and photography are analyzed obtaining quantifiable, reproducible and trustworthy data. There are different options of software to carry out this type of evaluations such as PAS/SAPO, AutoCAD, Matlab, ImageJ, Adobe Photoshop, AL Cimagem 2000, CoreIDraw, Peak Motus motion analysis system, Kinovea, BioPrint of Biotonix among others. Among some disadvantages of this method, it is notorious that due to the big amount of available software, there is no protocol standardization, which makes it difficult for clinical, research or public health use.

Moiré’s topography: this is a method using patterns of Moiré on the body surface to make a posture evaluation. To generate these patterns, it is necessary to use a light that projects through a grid on the body surface, the anatomic reference spots are marked and then, a picture is taken in order to be analyzed by physical therapy specialists [15].

Quantitative measurements allow health care workers in general and researchers carry out a precise evaluation on posture readjustments and keep track of its evolution in order to value the impact of its treatments. However, more studies are necessary in order to validate and calculate the reliability of each and every of these systems.

This research used the photogrammetric method and presents the results obtained when comparing the processing of images obtained with three different photographic cameras located at different distances from the subject. For the processing of images, an application of software was developed, capable of performing posture evaluations automatically. The development of the app was carried out with the software Matlab considering frontal anterior and posterior plane, and right lateral sagittal plane. The app performs a “marker automatic measurement” (LAM by its Spanish acronym) through filtering and segmenting of markers in photographic images. Once these markers have been formatted, a numerical algorithm is applied and posture parameters results are obtained in charts where they are synthesized in order to give the physical therapist’s diagnosis a quantitative and objective contribution.

II. METHODS

A. Anatomical points and posture parameters definition

In order to develop our proposal, we started from identifying and marking the reference spots of the human body. There are several studies where they try to identify the important anatomical points in a posture evaluation. Singla et al. [8] performed a revision of the literature to establish important posture angles in a photogrammetric evaluation of the upper body for head, neck, shoulder and thorax posture

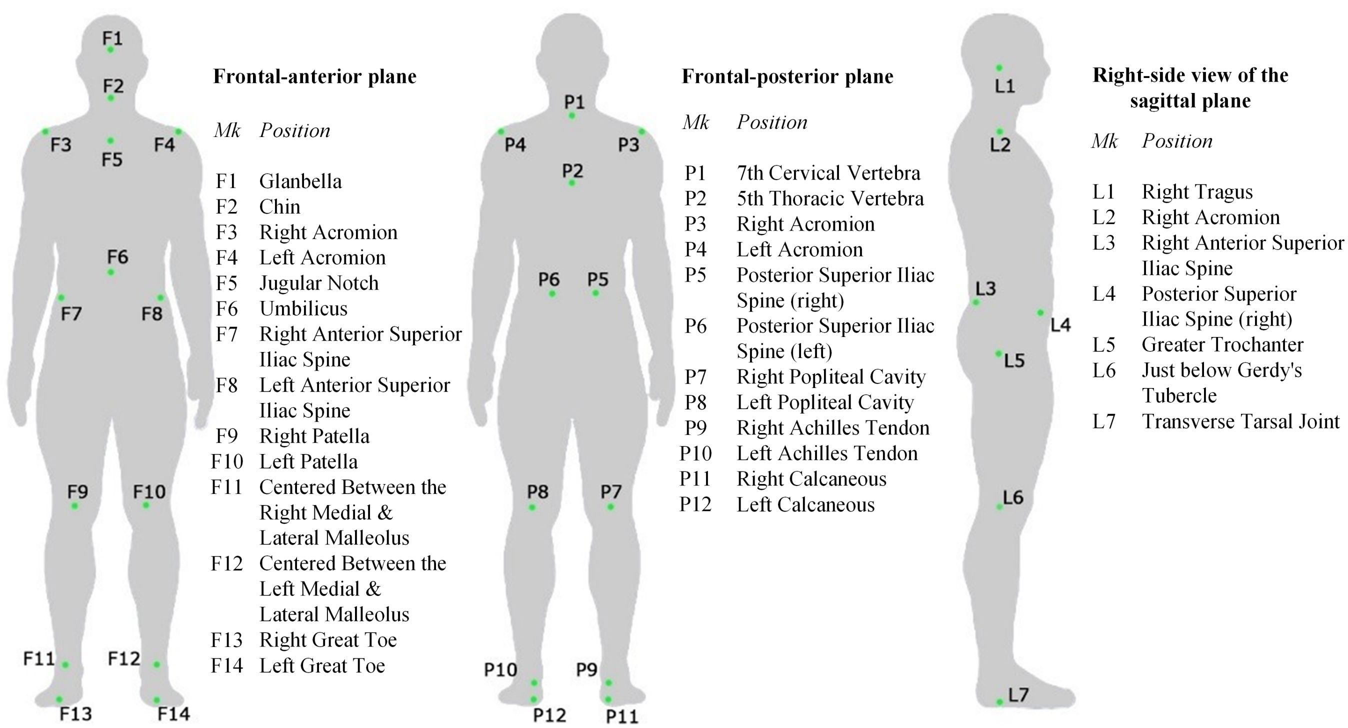

Fig. 1. Reference and the numeration of the anatomical points for the frontal-anterior plane, for the frontal-posterior, and for the right-side view of the sagittal plane.

evaluation. A similar approach, but applied to the whole body considering the frontal and the sagittal planes is presented in [1]. Based on this data as well as the experience of the specialist of HABILITAR Physical Therapy and Neuro-rehabilitation center, located in Cuenca – Ecuador, anatomical points considered for the development of the app are shown in the figure 1.

On the defined anatomical points, green, round, adhesive tags are put, each one of 1.5 centimeters of diameter. The parameters required by the physical therapist to support a diagnosis are synthesized in tables.

The first corresponds to the frontal-anterior plane, another frontal-posterior plane and the last sagittal-right plane. The parameter descend-angle will show if one of both sides of anterior view (right or left) is misaligned regarding the opposite side and its magnitude in degrees. The second parameter, direction-distance, represents the distance from the anatomical point to the vertical line of reference (crown to rump axis) and its length in centimeters. Finally, the parameter direction-angle in the third part shows external and internal rotation of the foot and its magnitude in degrees. Concerning to the frontal-posterior plane, the parameters and its representation are the same with the difference that the final parameter direction-angle shows if the person has a varus or valgus foot. In right-sagittal plane, the parameter direction-angle represents the tilting of the body segment regarding the reference axis. The implementation of numerical algorithms was supported with the bibliographic revision in order to have an objective vision at the moment of developing an application and show the results.

B. Photo Shooting

For the photo shooting, the following variables were analyzed: type of camera, height of the camera and distance between the participant and the camera. The photographs were taken using three different cameras: a semi-professional camera (Nikon configured in autofocus mode, with the flash on and off), a mid-range cellphone camera (Xiaomi Redmi Note 5 pro hold the default configuration with the flash off and on) and a sports camera (Action Cam SJ7000, the photo resolution was set to the highest (14 MP), the photo quality in High and the ISO in automatic, the other settings were kept by default). The state-of-the-art reveals that the distance between the camera and the subject varies from 1.50 to 3.00 meters, and the height of the camera from the ground varies from 0.90 to 1.20 meters [11], [12], [16]. In the photographs, the participant has markers placed in the anatomical points defined in figure 1. The photos were taken using a tripod located to: 2.50, 2.00 and 1.80 meters from the subject, and the lens at a height of 1.10, 1.00 and 0.97 meters respectively with an illuminance of 29.92 lux.

Subsequent tests were conducted with thirty people from three different age groups: 10 children (9.40 $\pm$ 1.50 years), 10 adolescents (14.30 $\pm$ 1.50 years) and 10 adults (33.80 $\pm$ 16.60 years). The tests were performed at the HABILITAR center. All adults and children's representatives who participated in the trials were fully informed of the study objectives and all signed a voluntary, informed consent. The results obtained through the LAM system were contrasted with the photogrammetric evaluations carried out with the Kinovea software.

C. Digital filters and segmentation

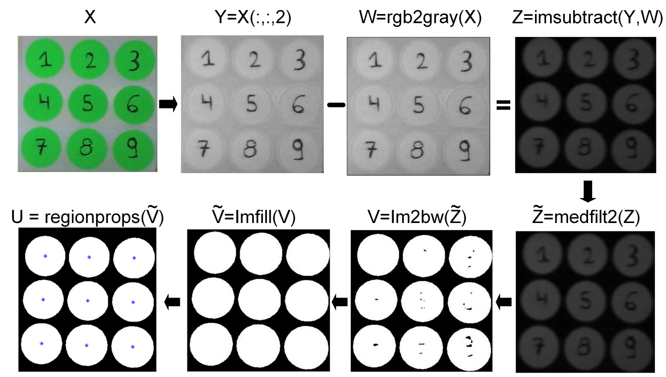

Fig. 2. Application of digital filters on the original image in order to improve the automatic measurement between points.

The software application for image processing was carried out in Matlab 2017b. First, an algorithm was developed to filter and segment the markers of the selected anatomical points. When you import an image (X, figure 2), it breaks down into three channels: red, green and blue to extract only the green channel from the matrix that composes the scanned image using 8 bits. By extracting only one channel, the resulting image is displayed in monochrome form (Y, figure 2).

To obtain the markers found in the photograph, the original image is transformed to grayscale (W, figure 2), and this is taken from the green channel that was previously extracted, getting as the result the image Z into the figure 2. To clean the noise image and improve the resolution of the markers, a median filter was applied in a 3-by-3 neighborhood ($\tilde{Z}$, figure 2).

Having the filtered image, the resulting matrix is binarized (V, figure 2). It is possible that there are holes in the middle of the markers, so it is necessary to fill them ($\tilde{V}$, Figure 2). Finally, it is necessary to locate the centers of each of the markers (U, figure 2) subsequently, depending on certain criteria of location in the plane, label each of the markers with the anatomical point that they must represent.

D. Parameterization

To label the markers with their respective anatomical point, the matrix of centers was ordered, according to certain location rules for each view, having prior knowledge that the points are ordered from left to right. Moreover, additional points were included through software, points derived from those already established and other points as a reference to generate a grid that will allow the physical therapist to have a visual reference and to obtain the scale factor to convert the pixels to centimeters. These additional points are located

TABLE I

MEASUREMENTS OBTAINED USING A REFERENCE GRID ON WALL AND USING DIFFERENT PHOTOGRAPHIC CAMERAS AT DISTANCE = 2.5 METERS AND HEIGHT = 1.10 METERS. *THE MAXIMUM ERROR WAS MEASURED USING THE SEMI-PROFESSIONAL CAMERA WITH FLASH ON.

	Grid on wall	Semi-professional		Smartphone		Max. Error*
		Flash On	Flash Off	Flash On	Flash Off	[%]
Angle from horizontal [deg]						
Shoulders	-21,70	-21.62 ± 0.09	-21.59 ± 0.05	-21.76 ± 0.09	-21.79 ± 0.13	1.89
Pelvis	0,00	0.01 ± 0.07	0.04 ± 0.07	-0.02 ± 0.05	-0.04 ± 0.05	0.09
Knees	-9,37	-9.30 ± 0.07	-9.27 ± 0.07	-9.63 ± 0.11	-9.64 ± 0.11	2.35
Distance from vertical [cm]						
Forehead	5,00	5.06 ± 0.04	5.06 ± 0.02	5.14 ± 0.10	5.15 ± 0.08	2.00
Shoulders	2,50	2.54 ± 0.02	2.54 ± 0.02	2.60 ± 0.10	2.57 ± 0.11	2.00
Umbilicus	-3,00	-2.97 ± 0.02	-2.97 ± 0.02	-2.95 ± 0.10	-2.93 ± 0.10	1.67
Pelvis	-2,50	-2.47 ± 0.02	-2.47 ± 0.02	-2.43 ± 0.05	-2.45 ± 0.07	0.03
Knees	0,00	0.01 ± 0.03	0.01 ± 0.02	0.00 ± 0.03	-0.01 ± 0.04	5.00
Toes	3,50	3.45 ± 0.03	3.45 ± 0.02	3.52 ± 0.05	3.52 ± 0.03	2.57
Angle from vertical [deg]						
Left foot	-11,37	-11.80 ± 0.14	-11.82 ± 0.12	-11.34 ± 0.31	-11.33 ± 0.20	6.77
Right foot	26,68	27.06 ± 0.11	27.08 ± 0.13	26.57 ± 0.30	26.49 ± 0.25	2.55
Inclination of the head	45,29	45.48 ± 0.12	45.51 ± 0.14	44.84 ± 0.14	44.97 ± 0.22	2.12
Right knee	9,51	9.88 ± 0.03	9.88 ± 0.04	9.28 ± 0.10	9.28 ± 0.11	5.47
Left Knee	11,35	11.78 ± 0.08	11.76 ± 0.05	11.04 ± 0.26	11.15 ± 0.06	5.11

one on each side of the person and separated by a distance of 100 centimeters (R1 and R2).

Each of the points has two coordinates, an X coordinate for the horizontal axis and a Y coordinate for the vertical axis. Since the coordinates obtained with the program are in pixels, the result of the distance will also be in pixels, thus it is necessary to convert these distances to centimeters using the distance between R1 and R2 as a reference. The results are saved in an individual report with the information of each participant and in an Excel database.

III. RESULTS

For the preliminary tests, markers were placed on a posture grid, simulating a patient in the anterior view, and then the photographs were taken. The marker ratios were measured manually using a tape measure (table 1, column-Grid on wall). The results are positive or negative, indicating the corporal segment orientation (right / left, varus / valgus, and external rotation /internal rotation respectively).

The table 1 summaries the average measurements that were obtained using different cameras. Eight measurements were performed with each camera, without daylight because it can change at any time and alter the measurements. Unfortunately, the tests using the sport camera showed low quality in poor light conditions avoiding to continue with the digital process due mainly to the distortion generated by the wide angle of the camera (fisheye).

To establish the maximum error of the measurements, showed in the right column of the table 1, tests were carried out using only the semi-professional camera, since in most cases it gave better results (table 1). Nine tests were developed, combining three different distances from the subject and three different heights of the camera.

For the tests performed on patients, all the measurements were developed with the LAM system and the Kinovea software. Contrasting the results, the maximum difference in angle measurement is 0.76 degrees from the vertical in the children group and the maximum distance difference is 0.64 cm in the adolescent group (table 2).

TABLE II

MAXIMUM DIFFERENCE OF MEASUREMENTS, CONTRASTING THE LAM SYSTEM WITH THE KINOVEA SOFTWARE.

	Adults	Adolescents	Children
Angle from horizontal [deg]	0.40	0.60	0.70
Distance from vertical [cm]	0.53	0.64	0.54
Angle from vertical [deg]	0.70	0.60	0.76

IV. DISCUSSION

Previous studies have developed alternatives for measuring body parameters using the photogrammetric method. Although the measurements are objective, they do not often adapt to the physical therapist's requirements or the requirements of the measurements that are attempted. From the revised proposals, few accede to adapt the system to the requirements of the specialist and need an additional calculation to determine the required parameters. Few works have addressed the perspective of the end user and the ease of acquiring the appropriate camera used in test laboratories. It is important to know how much the different variables involved in the photo shooting and its processing stage. In our work, we carried out different tests to know what is the contribution and the error that the different changes in the photography instrument or in the environment bring to the results.

The algorithm developed for the processing images in the system had several proposals because the filtering and segmentation of the markers was expected to be reliable and executable in other software. The principles of photogrammetry applied in the system do not rebuild a three-dimensional image or with depth levels, because only one photo of each view was used for analysis. These principles were applied only on the plane instead, as other programs, which perform postural evaluations do such as Kinovea, PAS/SAPO [12] or BioPrint.

The application was quite efficient in its task, as can be seen in table 1. Comparing the photographic cameras used to obtain the measurement, it is possible to find that semi-professional camera (flash on) generated images where the results have a value close to the manual measurement with lower variability. Such is the case of angle measurement from the horizontal. The distance from the vertical, the semi-professional camera presented better results and less variability in all reference points. Regarding the angle from the vertical, the results show that the smartphone camera with the flash off presents results closer to manual measurement and with lower variability; however, semi-professional camera measurements are no different from manual measurement. Comparing the results of table 1, it can be concluded that using a semi-professional camera is the best option to obtain more accurate results, with a maximum error of 3.89%; however, it is important to consider that the tests were carried out under poor light conditions, which allows us to clarify that in an environment with better light, the measurement error will decrease. It is also important to consider that the error in the measurements of the images obtained by the smartphone camera with the flash on is not greater than 4% with an average error of 1.81%. For this reason, both a semi-professional and smartphone cameras could be used as an image capture device with the LAM system.

Varying the location distance and the height of the camera, it can be seen that the maximum error is 6.77% (left foot angle from vertical), or 0.76 degrees, when the camera was located at 1.8 meters and at a height of 0.97 meters. The error was reduced by separating the camera 2.5 meters from the person. Regarding the height of the camera and the error that it introduces to the measurements, this does not exceed 1.01%. For the correct operation of the LAM system, it is recommended to place the camera 2.5 meters away from the person's location and place it at a suitable height for the person, in our case a height of 1.1 meters presented the best results.

The traditional method measurements could not be compared with that of the LAM system, for it is a subjective method; the way in which people's posture was interpreted varied greatly, as this depended on the expertise of the person who performed the posture evaluation. Additionally, the format of results of the traditional method is far from the results generated by the proposed system. In the end, the proposed system was compared with measurements made in the Kinovea software. The biggest drawback of testing with this software is the accuracy and time it takes to analyze each of the photographs.

From another perspective, using the Kinovea software, the time it took to make each evaluation for the frontal-anterior plane was 15.6 ± 2.6 minutes, in the posterior view was 15.3 ± 1 minute, and for the right lateral sagittal plane was 10.7 ± 1.8 minutes. With the LAM system, the three views were evaluated in less than a minute.

In conclusion, this study presents an adaptable and portable computational tool for body analysis in an agile and systematized way. The tests carried out allow visualizing the level of efficiency of the system and the numerical process developed internally in the software is detailed. The analysis of the different variables involved in the process of acquiring an image is described in such a way that the user of the system can replicate the results with a level of error similar to that established in this study.

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