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STRUCTURED-LIGHT 3D SCANNER IN USE TO ASSESS THE HUMAN BODY POSTURE IN PHYSICAL THERAPY — A PILOT STUDY

Abstract: Aim: The main goal of this study was to asses the possibility of using mass production structured-light 3d scanner to asses human body posture.
Material and Methods: The study was conducted on a healthy 23 year old volunteer and a lay-figure. The experiment consisted of 28 3D scans, divided into three separate tests.
Results: The largest deviation observed in the first two trials was 24.42 mm. While the largest deviation observed in the third trial was 49.91 mm.
Conclusions: Data obtained with the mass production structured-light 3d scanner may have comparable or better performance than commercially available systems for the assessment of BP.

Key words: 3D body scanning, body posture, clinical posture assessment.

INTRODUCTION

The human body posture (HBP) is a parameter evaluated and used by a large number of professions and professionals: doctors, physiotherapists, fitness instructors, designers of furniture, clothing, cars architects and artists. The list is probably endless.

Industrial sectors such as textiles have developed a number of tools to evaluate the HBP, but in the clinical setting the observation method of the body by a clinician continues to dominate and has demonstrated very low accuracy in numerous clinical trials [1].

Assessment of HBP in patients seems to be a very important diagnostic element because of the growing number of evidence connecting posture with pain [2–7, 1, 8–12].

The need for classification and parametrization of HBP appeared very early with one of the most famous manifestations of this need being the drawing of the "Vitruvian Man" from 1490 by Leonardo Da Vinci.

Classical description of posture proposed by Kendall [13] assumes full symmetry and proper relations of particular anthropometric points in the vertical line drained from the external auditory canal or the external occipital protuberance [9], this methodology is, however, qualitative and not quantitative, based on a two-dimensional reference system whose clinical usefulness has been questioned [3].

Generally accepted method of assessing human body is anthropometry but it has a lot of disadvantages: it is time consuming and requires a lot of experience on the part of the clinician [14]. Modern methods greatly automate the entire process of measurements [14], however, clinician still needs to manually find each anthropometric points and mark it on the body, which is affected by a large margin of error [15].

The biggest problem of anthropometric measurements is the fact that they provide only the distance between the points and not the location of the anthropometric points in the three-dimensional reference system.

METHODS OF IMAGING HBP

Several different imaging methods of HBP have been developed, which are based on the following technologies:

- Photography Method: posturepro (http://www.posturepro.com/) posturescreen (http://postureanalysis.com)
- stereophotographic method based on passive or active markers (Vicon, BTS smart, NDI, Zebris)
- methods of imaging surfaces (Cyberware, Exact3dscanner, Vitus)
- methods of imaging surfaces based on the depth camera (Kinect, PrimeSense, Asus Xtion)

The Photographic method is the simplest and cheapest method, and recommended for use in clinical situations by some scholars [5]. However, it is often called into question the clinical usefulness of this method due to poor accuracy and low reproducibility [3].

The Stereophotographic method, widely used in the motion analysis system which is based on markers apparently gives a very high accuracy of 1 mm or less [16]. However in practice, due to errors in placement of markers and tissue mobility the accuracy of this method is reduced to 40 mm [17–19, 6] This method is influenced by the experience of the person locating the markers on the patient, which becomes the main a source of error. These systems appear to be sufficiently accurate for clinical use [20], however, the space needed for the cameras, time required to make measurements and location of markers, as well as the high price of these systems make it applicable to research labs only. Thus they are hardly used in the clinical practice [20].

The most advanced imaging technique is based on the HBP surface reconstructions to a form of complete three-dimensional model. This method does not require sticking markers thus allowing you to acquire results within a few seconds and is free from any errors related to imprecise location of markers [21]. However, the current price of this 3D scanner technology exclude it from clinical use [22].

The last method is based on technology developed during the 70's of last century. It only started to be common in 2010 thanks to Microsoft Kinect which set a Guinness world record for the fastest-selling consumer electronic device [20].

Initially Kinect only allowed for control of the Xbox console using body movements. However, in 2011 Microsoft created a package of "Kinect for Windows SDK" which allowed use of Kinect by Windows software [23]. Thus many cheap computer programs were now able to create 3D models using Kinect like reconstructme QT [24] Skanect [25], Kscan3d [26].

CONSTRUCTION AND OPERATION OF STRUCTURED-LIGHT 3D SCANNER

The device has two cameras; infrared and accelerometer. The first camera is a standard RGB video camera, with a resolution of 640×480, while the second camera is part of the subsystem sensor, requesting information on the depth (Fig. 1). The Infrared camera works by displaying a cloud of points in front of the camera itself, whose positions are then recorded with an infrared filter. The resulting resolution of depth information from the camera is 300×200 and is software interpolated to the resolution of the vision camera (640×480). Range of the sensor is within 0.4–6.5 m. Distance information at all points of the program makes it possible to detect the human figure and his gestures. The use of structured light method allows for flawless operation of the sensor only indoors — reading is sensitive to excessive sunlight [27].

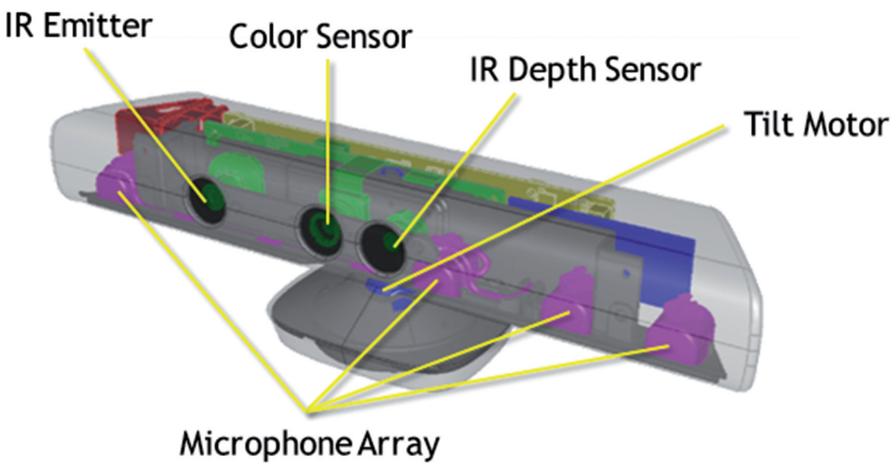

Fig. 1. Construction of structured-light 3D scanner.

PURPOSE

In this study we don't intend to provide statistical analysis of reproducibility, accuracy, precision, error, attitude, and image of technical errors. The pilot aims to present a new way of presenting changes in posture to clinicians. According to the authors it is characterized by significantly higher clinical utility than previously used methods based on anthropometry which present the results in tabular form, or as in the case of systems based on markers presenting a three-dimensional skeleton formed from the anthropometric points.

The authors would also demonstrate that the technology and the methodology is sensitive enough to detect changes in body posture.

MATERIAL AND METHODS

Ethical approval to conduct the study was obtained from relevant authorities.

The study was conducted on a healthy 23 year old volunteer and a lay-figure. The experiment consisted of three separate tests:

The first test consisted of 10 measurements performing posture relaxed. After each measurement a few minutes' rest was given to the volunteer.

On the ground we have marked the outlines of the foot with adhesive tapes to ensure every measurement was taken from the exact same location (Fig. 2).

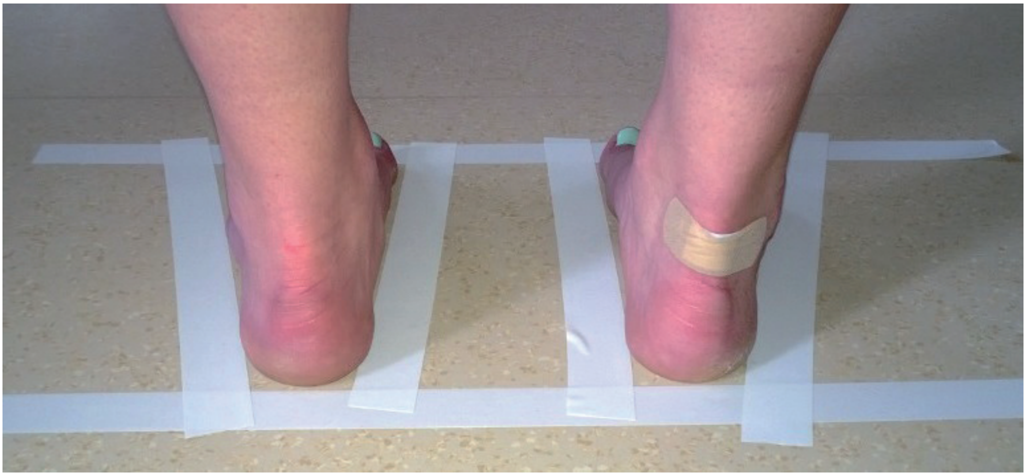

Fig. 2. Marking foot positions.

The second sample consisted of 10 measurements performed by lay-figure in exactly the same way as the volunteer.

The third trial consisted of eight measurements, during which the volunteer was asked to take on a particular posture and keep it for the duration of the scan:

- measurement 1 — volunteer was instructed to adopt a relaxed posture
- measurement 2 — volunteer was instructed to "lift left shoulder"
- measurement 3 — volunteer was instructed to "stoop"
- measurement 4 — volunteer was instructed to "straighten up"
- measurement 5 — an object with a height of 5 cm was placed under the left foot of the volunteer which stimulated limb shortening
- measurement 6 — volunteer was instructed to inhale and hold their breathe for the period of measurement.
- measurement 7 — volunteer was instructed to exhale
- measurement 8 — volunteer was instructed to put a bag on their right shoulder

The scanning procedure began by placement of Kinect at a distance of 1 m from the volunteer at the level of the pelvic region. The therapist moved along a circle trajectory, at the center of which the volunteer was placed, doing the slow motion of the sensor checking on the computer screen the recorded image.

To create a 3D the following systems were used: the reconstructme QT software version 1.2.103 with the parameter set to "Scan Area" on "Human Standing High Detail", and a computer Acer Timeline M3 with Intel Core i3, 4GB of RAM and a graphics card nvidia GForce GT 640m 1 GB, the Windows 7 operating system. An active USB extension cable with a length of 5m was used to connect the sensor to the computer. This configuration made it possible to get a scan rate of around 10–12 frames per second.

The resulting scan slt was exported to a format which was then imported onto the GOM Inspect V7.5 SR1.

In all tests the first measurement imported was treated as a template and the other compared the measurements. The program GOM Inspect used functionality "import" with the parameter "Target element type" as "CAD body" for the measurement model. Then further measurements were imported by selecting for each parameter "Target element type" as "Mesh".

The next step was to overlay measurements using the functionality of the "Operations > Alignment > Initial Alignment > Prealignment", using standard settings.

The next step was to visualize differences between individual scans which used the following functionality "Inspection > CAD comparison > Surface Comparison on CAD ...", as a result of this operation, the differences between the measurements are being imaged on the measurement reference. A red color represents the shift in the space which have positive values, while in blue were the negative values.

The next step was an indication by labeling with the values of the area of maximum displacement. The smallest deviations were used for this functionality: "Inspection > Deviation Label...".

RESULTS

In Experiment No. 1. the largest deviations were observed during the No. 8 test for the hand, which were 24.42 mm, and 20.29 mm for the occipital region. During this measurement the patient is moving so that is possible source of these values, other measurements limits are presented in Table 1.

Table 1

Maximum deviation in trial no 1.

# measurments	Maximum deviation (mm)	Region
1	14.85	Suprascapularis left
2	15.03	Occipital
3	21.30	Acromial
4	16.41	Left hand
5	14.51	Sural
6	14.43	Buccal
7	19.95	Sacral
8	24.42	Forearm
9	20.86	Right hand

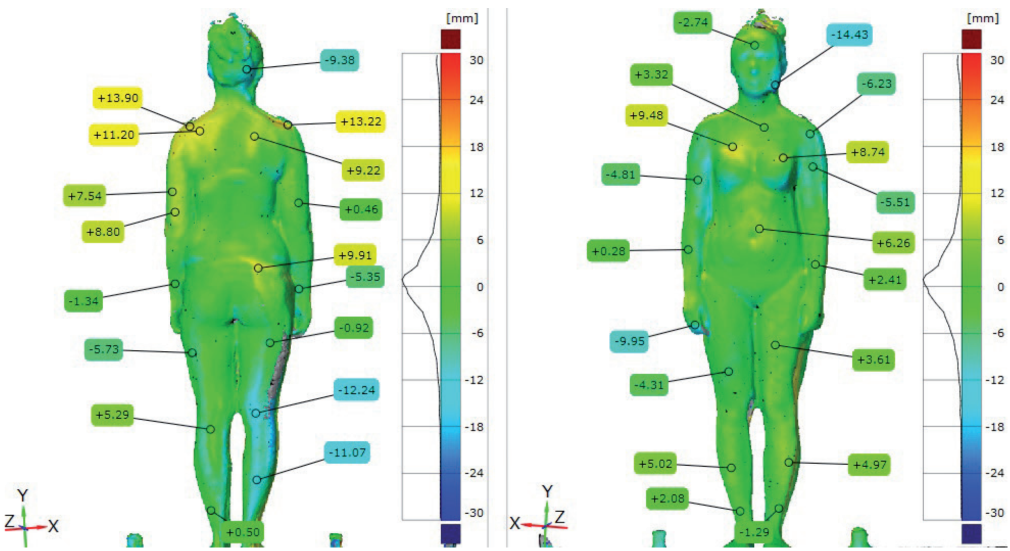

Fig. 3. Scan number 6, trial 1.

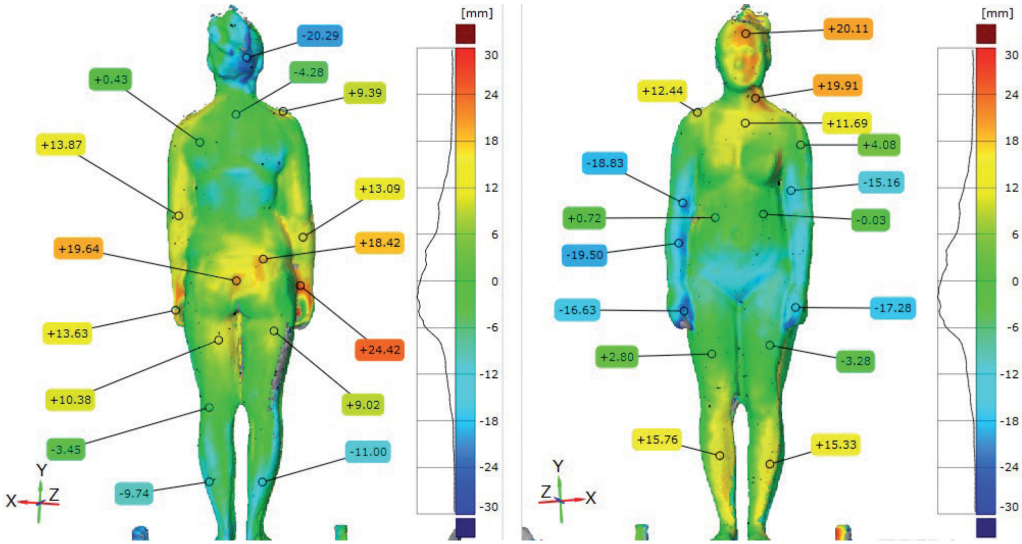

Fig. 4. Scan number 8, trial 1.

Figure 3 presents the measurements for test no 6, which displayed the smallest deviations. Figure 4 shows the measurement with the largest deviations.

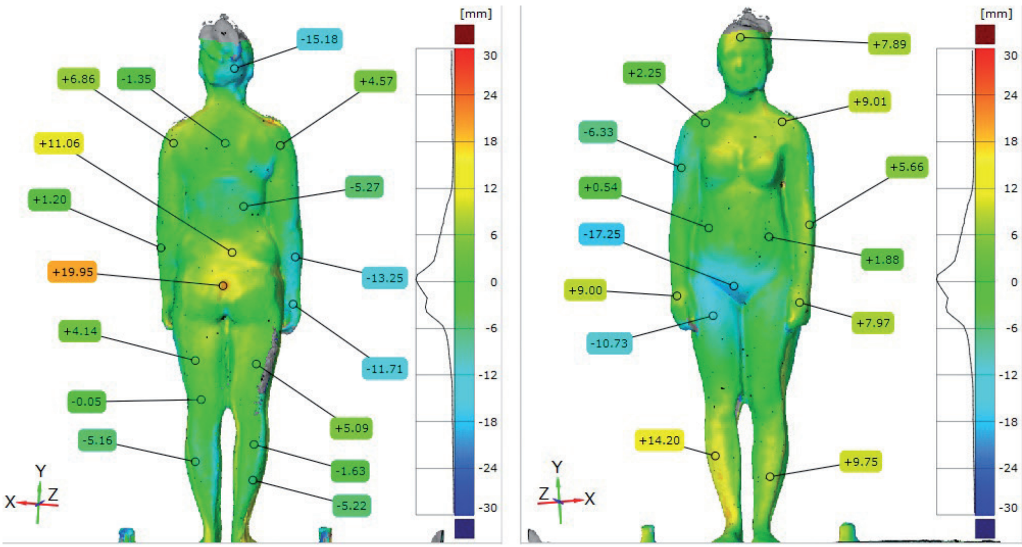

Fig. 5. Scan number 7, trial 1.

Figure 5 presents the measurement of test no 7. Pay attention to the fact that at the front side of the body in the pubic region there is a deviation with a negative value of 17.25 mm and at the rear side in the sacral region a positive deviation of 19.95 mm. This was similar to the situation in measurement no. 8 in which the patient moved. The maximum deviation was observed on the forearm but it reaches high values in the occipital and frontal as well-20.29 20.11, refer to Figure 4.

The second trial used a lay-figure and achieved a maximum deviation of 31.69. However, after careful analysis of the scan it turned out, for unknown reasons that the rear surface of the calf and foot was not properly scanned. The second-largest deviation was observed during measurement 4, which was 15.46 mm, while a minimum deviation of 6.52 mm was recorded during measurement 8.

Table 2

Maximum deviation in trail no 2.

# measurements	Maximum deviation (mm)	Region
1	12.1	Occipital
2	10.35	Parietal
3	12.36	Occipital
4	15.46	Acromial
5	9.86	Olecranal
6	31.69 (14.01)	Left sural (frontal)
7	10.71	Frontal
8	6.52	Femoral
9	12.14	Parietal

Table 3

Maximum deviation in trail no 3.

Posture	Maximum deviation	Region
„left shoulder rise”	30.47	Left Acromial
„hunched over”	49.91	Left hand
„object under left feet”	31.15	Frontal
„upright”	38.23	Left hand
„expiratory”	24.32	Frontal
„inspiratory”	21.53 (26.4)	Suprascapularis (left crual)
„bag on let shoulder”	24.22	Occipital

Figure 6 presents the results for the measurement in which the volunteer was asked to elevate the left shoulder. The greatest variation observed within the left shoulder was 30.47 mm. The right side of the head yielded a positive value (18.9 mm) while the left side displayed a negative value.

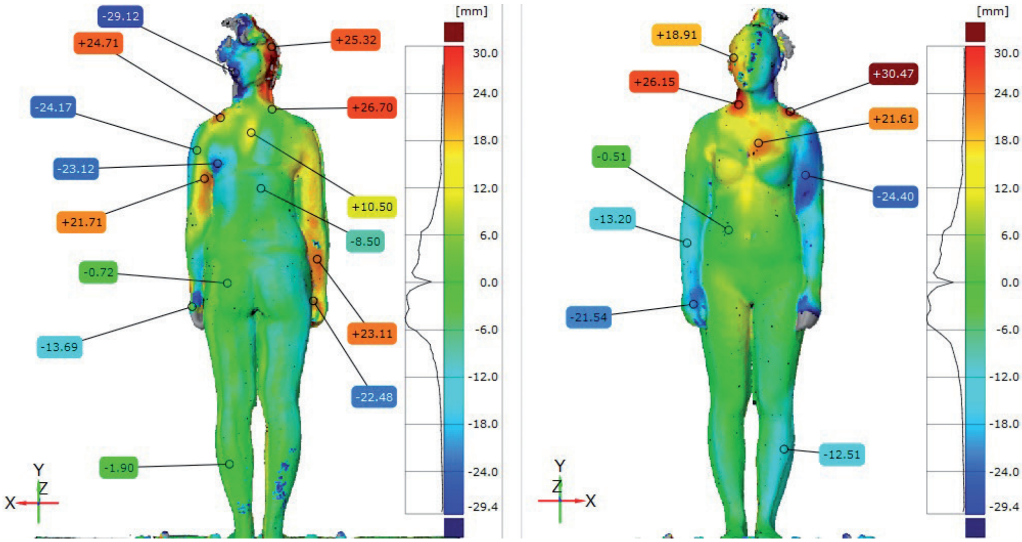

Fig. 6. Posture with “left shoulder raised”.

Figure 7 presents the results obtained during measurement in which the volunteer was asked to adopt a hunched posture. Obtained maximum deviations observed throughout the experiment. Negative values of –5 cm were observed on

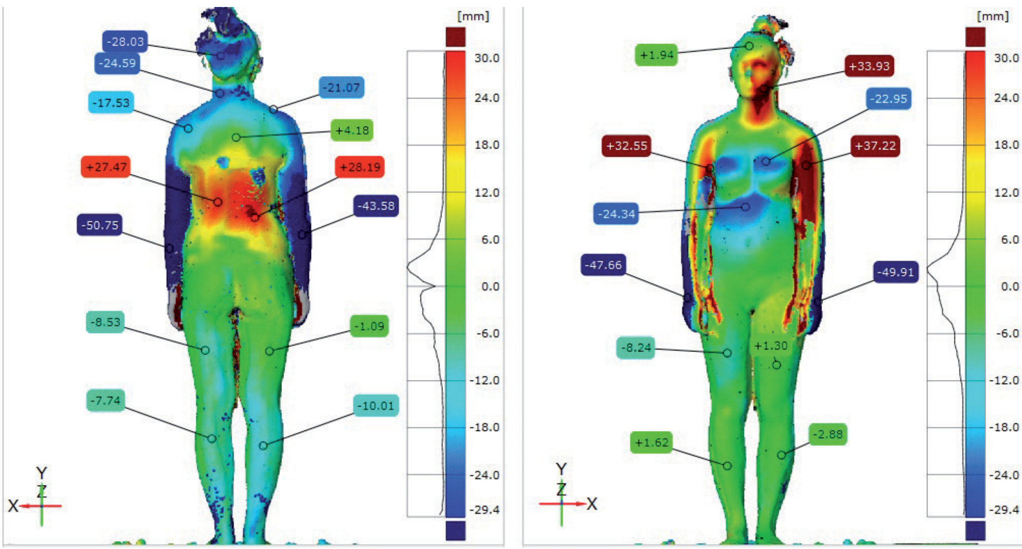

Fig. 7. „Hunched over” posture

the dorsal surface of both upper limbs, and deviations ranging between 2–3 cm were observed on the head, as well as around the lumbar thoracic and chest area.

Figure 8 shows the measurement in which a 3 cm object was placed under the left foot of the volunteer. This was done to simulate limb shortening as in functional scoliosis. During this measurement a positive displacement of the head

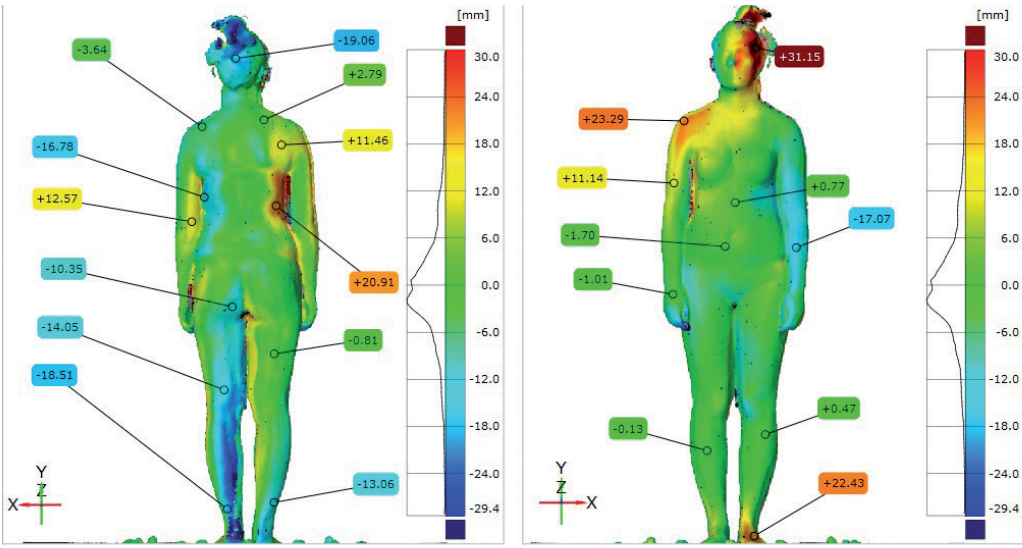

Fig. 8. Simulation of functional scoliosis — 3 cm object under left feet.

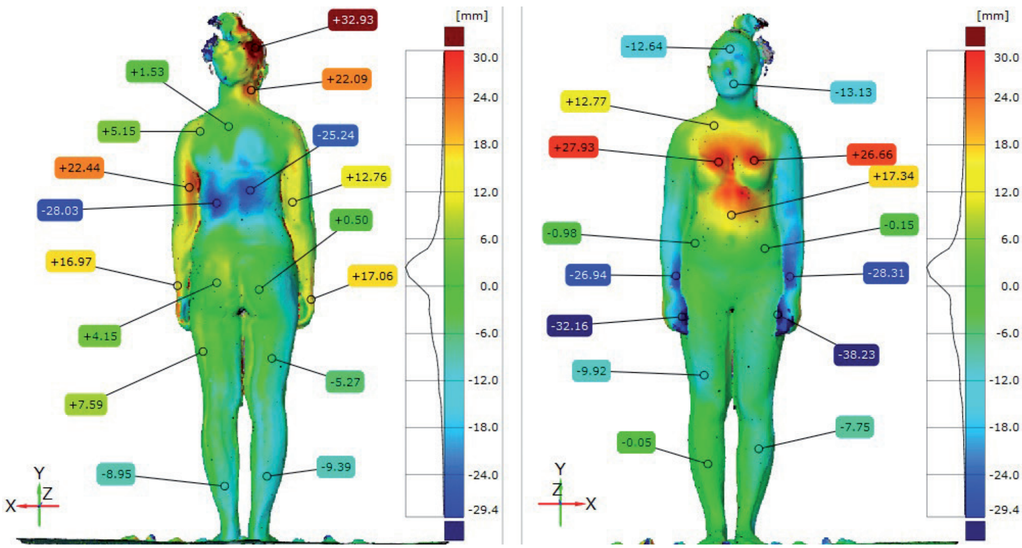

Fig. 9. “Upright” posture.

in the frontal area and negative displacement in the occipital area were observed. There was a positive movement of the right waist and negative movement of the left waist. There was also a negative shift of the entire posterior surface of the left leg but there was no positive shift seen for the anterior surface of the left leg.

Figure 9 shows the measurement in which the volunteer was asked to adopt an upright posture, there was a similar movement here as the hunched posture, but with the opposite direction of deviation.

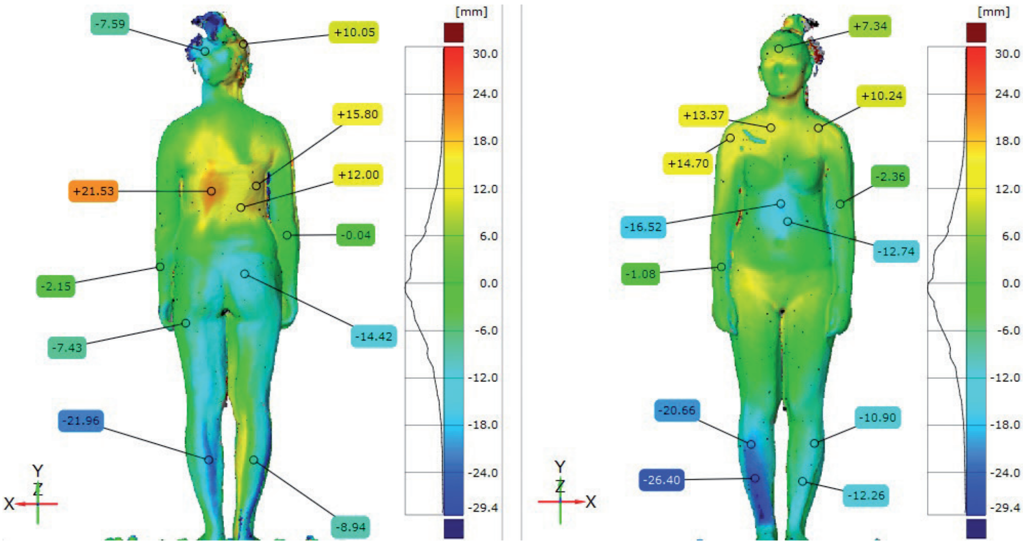

Fig. 10. “Expiratory” posture.

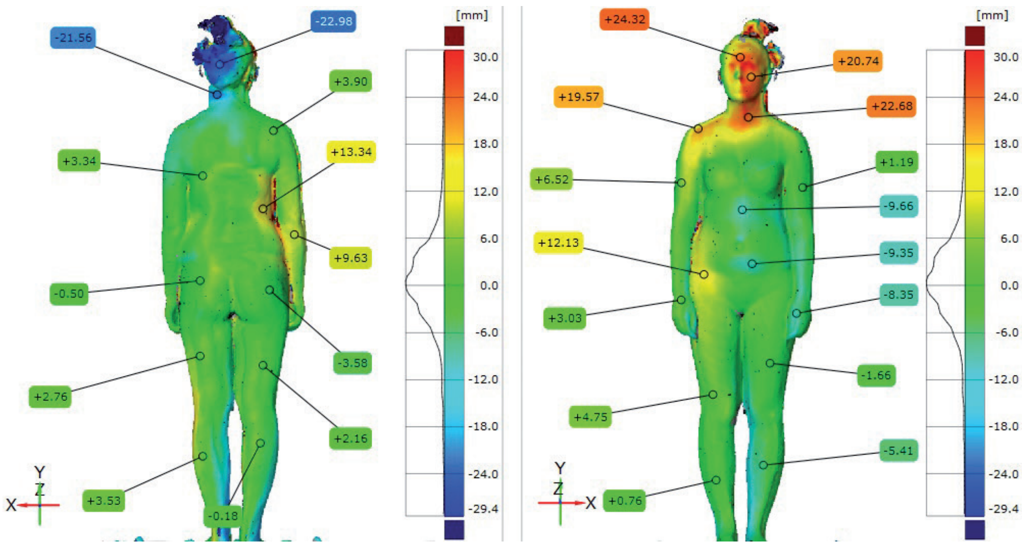

Fig. 11. “Inspiratory” posture.

Figures 10 and 11 present the posture in which the volunteer was asked to exhale and then inhale.

Exhaust posture resulted in displacement of the head by about 2 cm. Inspired posture caused displacement within the thoraco lumbar and abdominal areas.

Figure 12 shows the posture of the handbag inserted in the left arm. There was displacement of the head by 2 cm.

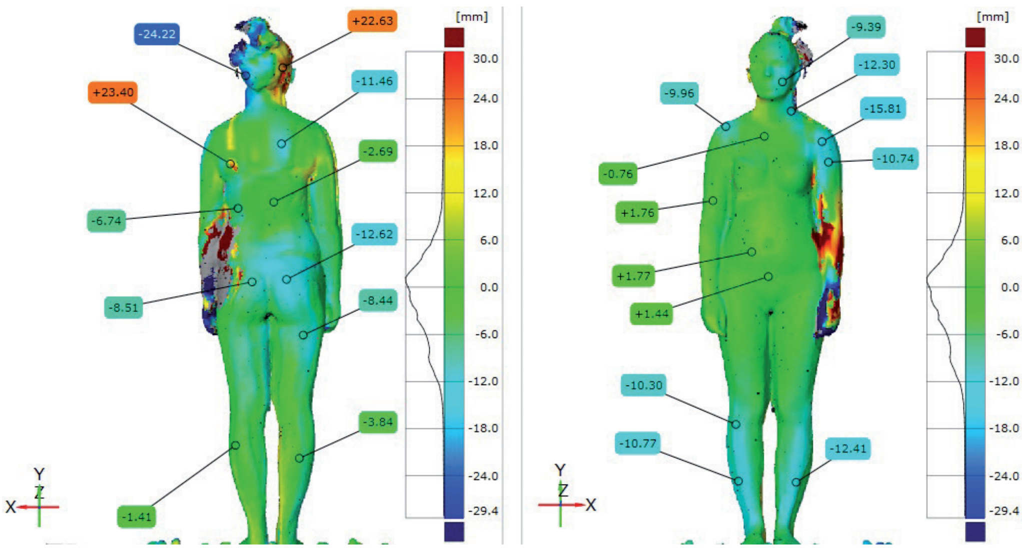

Fig. 12. Posture with "handbag on left shoulder".

DISCUSSION

The results did not show clearly that the adopted methodology provided reproducible results. The highest value of the first sample, except for the measurement of displacement 8 was 2 cm. This result was comparable to the accuracy obtained using the marker-based systems in which the accuracy of the deployment was in the range of 1–4 cm [16].

It should be noted that maximum deviation recorded during the test on the lay-figure was comparable to the minimum deviation registered for the volunteer. This situation may have been a result of the patient's natural swings associated with balance or due to the fact that the Kinect sensor achieved lower accuracy when scanning human skin in relation to the plastic skin of the lay-figure. This observation requires a further detailed testing stage.

According to [16] the required accuracy of the device is not unambiguous and depends on the intended use of the device. In case of clinical applications it is important that the actual clinical effects stand out from the noise [16].

Please note that the results obtained in experiment 1, 2 and 3 differ significantly. The differences and locations observed in experiment 3 were consistent with what would be expected when taking a specific posture in a clinical setting. If the differences in the results obtained from samples 1 and 2 came from natural human movements involved in maintaining body posture than the data collected by Kinect shows very high accuracy.

The artifacts generated during the scanning process were the main problem in relation to the interpretation of the results Figure 13. It is possible to reduce the number of artifacts by using a rotary platform on which the patient would be placed on during the trial. However, this correction may actually increase the patient's inclinations associated with maintaining balance.

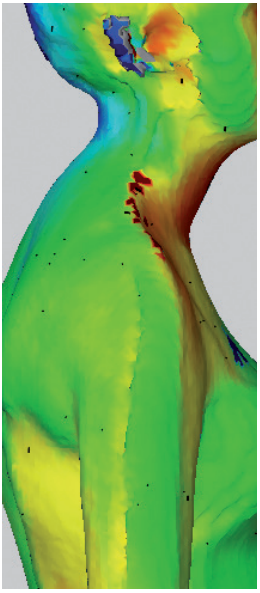

Fig. 13. Artifacts.

Potential sources of error are shown in Table 4.

Table 4

Source of error.

Name	Description
Artifacts	Error resulting from imperfections scanning software reconstructme
Posture error	Errors due to movement during the measurement, and trying to adopt the same posture
Software error	Error due to the algorithms to build up the two scans in the GOM Inspect

Regardless of the accuracy and technical parameters which need to be determined during the course of further research, it should be emphasized that present technology has a lot of advantages over commonly available systems. The cost of all the components for this system was comparably lower than the cheapest products on the market. The system is portable and capable of use in almost any physiotherapy practice. Presentation of the results does not require any further knowledge on the part of the clinician. In addition the color orientated presentation is very appealing and intuitive for both physical therapist and patient. This is very important because most of the expertises do not translate into clinical practice [28]. According to the authors this is due to the use of an incomprehensible language for clinical research.

CONCLUSIONS

Due to the small number of patients used in this experiment it is not possible to declare clinical utility of the technology and methodology of this study.

The results, however, give rise to initial evidence that the data obtained using the Kinect sensor and software reconstructme may have comparable or better performance than commercially available systems for the assessment of BP.

The mapping surface technology allows for the imaging of a color map on the body of a patient, which is much more friendly and intuitive than previously used forms.

CONFLICT OF INTERESTS

None declared.

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