Photogrammetry – principles of operation and application in rehabilitation

Fotogrametria, zasady działania i zastosowanie w rehabilitacji

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Authors' contribution: A – project of the study, work; B – collection of the data, information; C – statistical analysis; D – data interpretation; E – preparation of the manuscript; F – literature query; G – obtaining funds

Received: 20.07.2006; accepted: 15.02.2007

Key words
photogrammetry, rehabilitation, walking, posture, posture defects

Abstract
Photogrammetry is a method of measurement of a physical object by means of images. The term comprises registration of electromagnetic radiation in a wide range of wave lengths. Determination of location of a point in a three-dimensional space is the common principle for all methods. Photographs of the same point taken simultaneously from at least two locations constitute the basis of calculations. Photogrammetric methods used in medicine fall into two basic groups: evaluation of movement and assessment of changes on a surface. The presented principle of classification is very simplified. The real complexity of the idea is reflected by a great variety of measurement systems. So far, Moiré's system assessing the shape of the back has gained greatest popularity in rehabilitation. Methods assessing movement are much less **common** due to the prices of the equipment, necessity to use large rooms and being time-consuming. Fortunately, there has lately been an improvement in this respect. Depending on the capturing method, information about structure or movement can be obtained. None of the devices using most modern measurement technologies is able to examine both kinds of data simultaneously. The advantage of all photogrammetric systems is a large amount of information obtained; their disadvantage is a difficulty of its interpretation. Usefulness of measurement equipment requires presence of a system of data interpretation as an integral part of this equipment. Progress in rehabilitation depends on one hand on technical features of measurement equipment and, on the other hand, on rehabilitation specialists who will be able to formulate their expectations towards systems of movement measurement being newly developed.

Słowa kluczowe
fotogrametria, rehabilitacja, chód, postawa, wady postawy

Streszczenie
Fotogrametria jest pomiarem obiektu fizycznego przy pomocy obrazów. Pojęcie to obejmuje rejestrację promieniowania elektromagnetycznego w szerokim zakresie długości fal. Wspólna dla wszystkich metod jest zasada wyznaczania położenia punktu w trójwymiarowej przestrzeni. Podstawą do obliczeń są zdjęcia tego samego punktu wykonane jednocześnie przynajmniej z dwóch różnych miejsc. Metody fotogrametryczne, stosowane w medycynie, możemy podzielić na dwie podstawowe grupy: do badania ruchu i do oceny zmian powierzchni. Przedstawiona zasada podziału jest bardzo dużym uproszczeniem istoty badań fotogrametrycznych. O prawdziwej złożoności tematu świadczy wielka różnorodność systemów pomiarowych. Do tej pory największą popularność w rehabilitacji zdobyła metoda mory, oceniająca kształt pleców. Metody oceniające ruch są znacznie mniej popularne, ze względu na cenę urządzeń, potrzebę wykorzystywania dużych pomieszczeń i

czasochłonność pomiarów. Na szczęście, także i pod tym względem zachodzą korzystne zmiany. W zależności od sposobu patrzenia uzyskujemy informacje o strukturze lub o ruchu. Żadne urządzenie stosujące najnowsze technologie pomiarowe nie jest w stanie zbadać całości. Zaletą wszystkich systemów fotogrametrycznych jest duża ilość dostarczanych informacji, wadą – trudność w ich interpretacji. Żeby system pomiarowy był użyteczny, jego integralną częścią powinien być system interpretacji wyników badań. Postęp w rehabilitacji zależy z jednej strony od technicznych możliwości urządzeń pomiarowych, z drugiej strony od specjalistów rehabilitacji, którzy będą potrafili formułować oczekiwania wobec nowo rozwijanych systemów pomiarowych układu ruchu

What is a photogrammetric measurement?

Photogrammetry is a domain of technical sciences involving obtaining information about object shape, its spatial location in relation to other objects, and – possibly – about translocation or deformation of the object. Pictures created by means of photogrammetry can be recorded in different electromagnetic wave ranges: in the majority of cases, it is radiation within the visible range; however, near- and medium infrared, thermal infrared, microwaves, and X-rays are also used. Pictures are recorded by sensors appropriate for particular type of radiation (for the visible and infrared ranges – photographic cameras, video cameras, and scanners are used; for microwaves – special receivers and radars; for X-rays – Roentgen cameras).

Principal advantages of photogrammetry are:

- objective measurement thanks to remote data acquisition,
- no contact with the measured object,
- possibility of measuring any number of points on the photograms,
- photogram is an archived data file that may can be used any number of times,
- high measurement accuracy; for the so-called close-range photogrammetry (imaging distance shorter than 300 m), it is approximately 1/10 000 of this distance,
- a great variety of the measured objects and related phenomena obtained thanks to the possibility of recording within different wavelength ranges,
- recording of dynamic processes,
- at the current state of technical development – possibility of a fully automatic measurement.

To simplify, photogrammetric measurement involves reproducing of the trajectory of a ray running from the lens of the camera to the evaluated (being imaged) point by means of a camera (or scanner). Position of the point in a three-dimensional space is obtained by crossing a ray running to the same point but from another camera station (Figure 1). To resolve the measurement algorithm, at least two images from different points must be performed.

The majority of photogrammetric images are based on measurements of certain selected points on the picture. They are the basis to calculate the position of the measured points. This position is determined by coordinates in a three-dimensional reference system. Accuracy of the determined coordinates depends on many factors, such as: distance from the camera and the focal length of the camera lens, knowledge of camera characteristics, picture resolution constituting a measure of the imaged details, number and distribution of the performed photographs.

Selection of the measured points determines the photogrammetrically obtained type of information about the measured object – by measuring points located on the edges of a building, an edge model of this building will be obtained, while by measuring multiple points, also those found on its walls, the roof, a surface model of the building will be recorded. Identification of the same point captured differently by different cameras is a serious problem. In this case, an artificial stereoscopic effect is used that allows obtaining an effect of a spatial model based on appropriately performed photographs. In some cases, stereoscopy cannot be used and markers should be applied that unequivocally signal the measurement points.

Photogrammetry is a measurement tool that found multiple applications in various life domains. It is a domain that revolutionized construction of maps. Robotics also developed thanks to this technique. Photogrammetry enables the so-called machine-vision. Processing of digital images and their real-time measurement allows automatic performance of many complicated production processes.

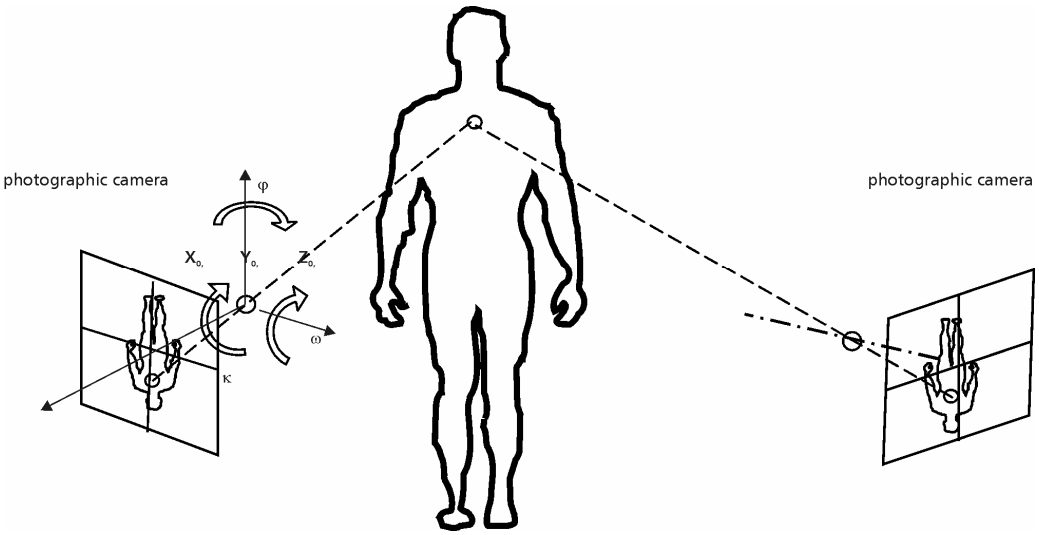

Figure 1

The principle of defining spatial location of a point using the photogrammetric method. Spatial location of point images can be obtained based on at least two images of the same object and the information on location of the cameras

Medical applications of photogrammetry

Photogrammetry has been used in medicine for measurements of human body for many years; yet, its techniques and methods were limited by the necessity to use expensive and sophisticated equipment requiring appropriate knowledge and skills by its operation. Methods enabling performance of a measurement by medical staff in a physician's office and obtaining results within a short period of time (duration of a visit at physician's office) have primarily a chance to be introduced in medicine.

Digital images in combination with a computer-assisted technique provide possibilities of fast acquisition, processing, automatic measurements and thus obtaining desired results within a short period of time.

The most frequently measured body parts, functions and associated phenomena:

- the face – monitoring of changes after cosmetic operations and in orthodontics,
- the teeth – examination of microdefects, and of the shape – for formation of prostheses,
- the skin – detection of melanoma, measurement of deep and widespread wounds for the purpose of grafting,
- the extremities – monitoring of the shape following surgery, measurements for prosthesis formation,
- posterior part of the body, especially the back – in examination of scoliosis and back curvature,
- posture analysis – in medical rehabilitation,
- motion analysis – in medical rehabilitation, sport medicine, sport and cinematography,
- internal body parts and their situation with regard to the external parts – positioning for cancer therapy, in telemedicine.

Whatever the common name, in each case, a separate measurement and data analysis system is needed.

Photogrammetry in rehabilitation

Methods of solid body assessment

The Moiré's method of stripes is widely known in rehabilitation. It involves performing photographs of bright and dark stripes displayed on the object that are formed by superimposing of two line families onto each other (Figure 2). A network of lines placed between the object and two different light sources projects onto the object two superimposing shades. Given the distances of light sources from the object and of the network from the object as well as dimensions of the line, object shape can be reconstructed.

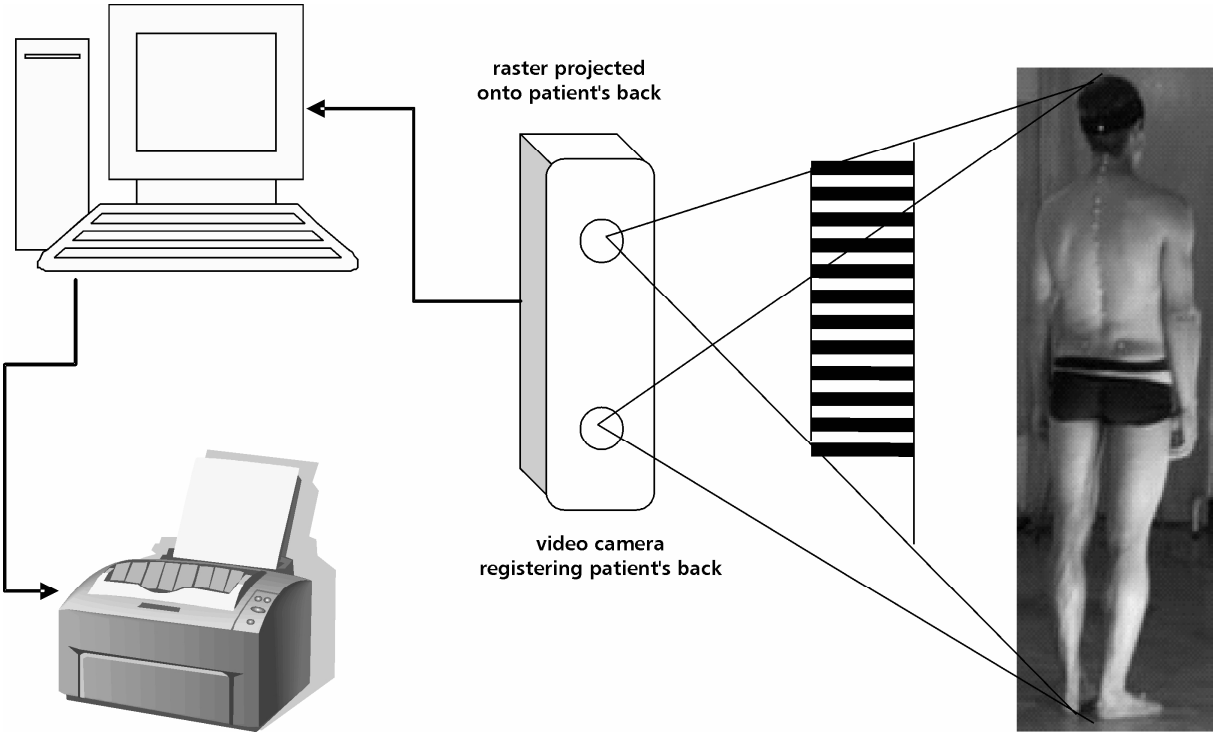

Figure 2
Moiré's stripe method of scoliosis examination

In many systems, points on the body surface are not a transposition of the internal points onto it, but serve to model this surface. As human body is (in general) smooth, its points are often signalled by projecting small stains, lines, or a network using optical projection (Figure 3). Renowned commercially available systems using this method include:

- - 3dMDface System, 3dMDcranial System, 3dMDhand System, 3dMDmacro Series (3dMD MQ Company),
- ASAP 3D Skeleton Model (ASAP).

Information about the shape of body surface can also be obtained by projecting a pattern onto it from a projector placed in a known position (Figure 4).

Examples of systems based on pattern projection include:

- Vitus 3D Body Smart (Vitronics),
- InSpeck 3D Full Body (InSpeck) - optionally,
- DIERS Formettric II (Diers),
- BLScanner (Hamamatsu),
- 3D Body Scanner (TC^2)

- SYMCAD (Telmat)
- TriForm Body Scanner (Wick&Wilson)
- 3dMDtorso System (3dMD a 3Q Company)

Hybryd systems using small stain projection or laser line of a given direction, but registering using CCD camera (Figure 5) can also be considered photogrammetric systems. Their disadvantage is several to twenty second-scanning time, the advantage – simplicity of the system and its easy automatic control. These systems are most frequently used in garment industry and cinematography, yet they can also be found in medical applications.

Examples of systems based on this principle:

- Head & Face Color 3D Scanner Bundle, Whole Body Color 3D Scanner Bundle with WB4 unit, Whole Body Scanner model WBX, Below the Knee Scanner (Cyberware),
- Voxelan (Hamano),
- Vitus 3D body scanner, Vitus Pro 8C (Vitronics).

Optic projection, pattern projection, and hybrid systems are used to describe the surface of a solid body and have similar applications to the Moiré's method.

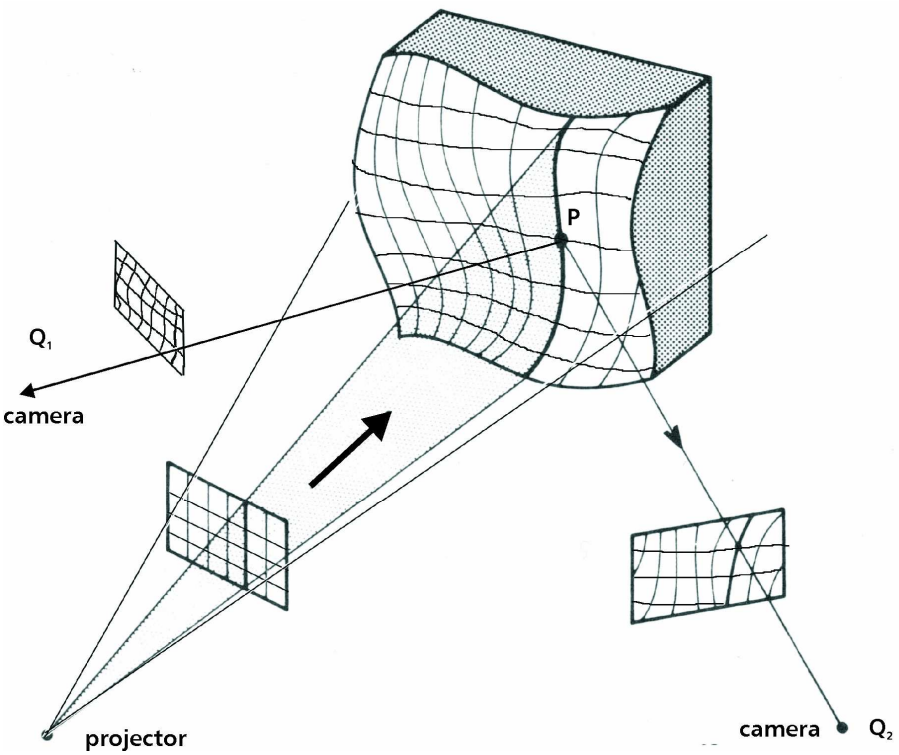

Figure 3

Signalisation of points on body surface by means of projection of a network of rectangles

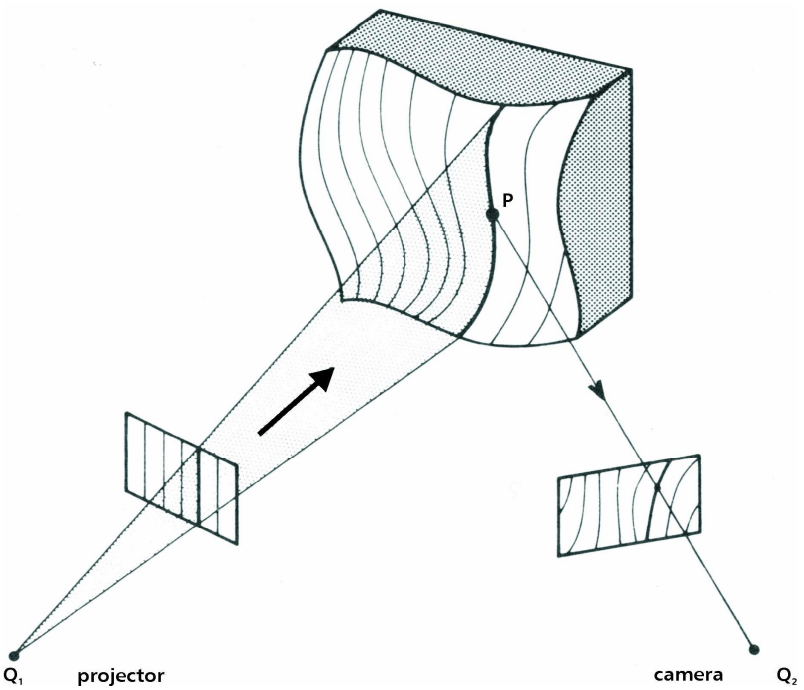

Figure 4
Principle of operation of the system based on light pattern projection

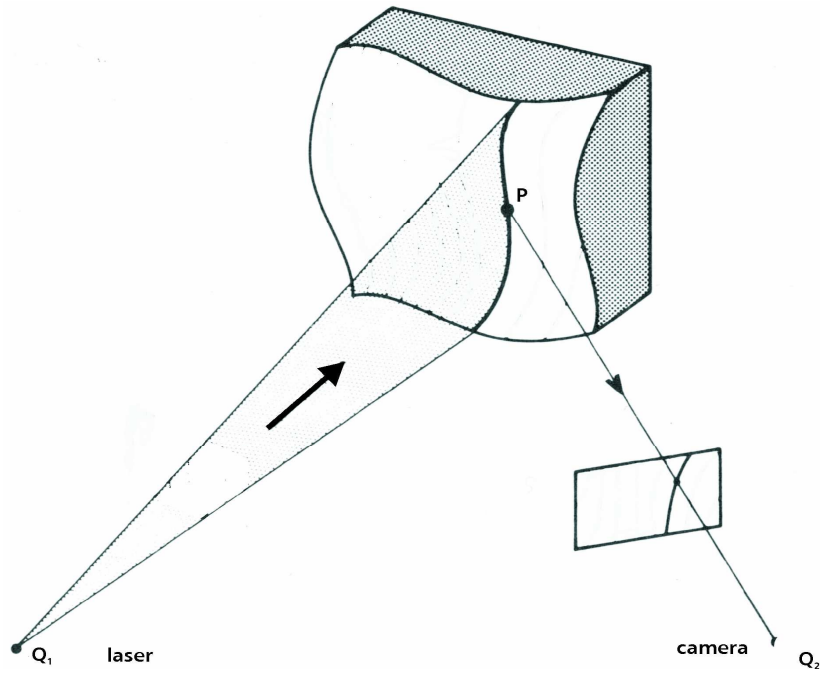

Figure 5
Principle of operation of the system based on the triangulation with laser scanning

Methods assessing motion

Coordinates of selected points of an object that are especial natural points or markers are the second type of information about the measured object. At this particular point, the technical problem becomes a medical one. Depending on the concept of measurement in different methods, different points on body surface are demarcated. Size of a marker and a possibility of precise, reproducible demarcation of the same point are of extreme importance for the accuracy and comparability of testing results. This type of data collection is applied in motion analysis systems. It uses three to seven (most often - five) digital cameras linked to a computer (Figure 6).

The cameras register position of the markers in the measurement space. Two types of markers are used: passive (reflecting infrared light emitted by the cameras) and active (emitting light flashes in a precisely defined order). Data transferred to the computer enable determination of the markers in a three-dimensional space. Special software allows calculation of characteristic parameters describing patient movements. Course of the evaluated curve is compared to a pattern (APAS System manufactured by the company Ariel Dynamics, Zebris, Vicon)[1].

The majority of photogrammetric studies record fragmentary, partial changes. Yet, it is known that disturbed motion within one segment is compensated by the other segments. Stabilogram of a person standing still on a tensometric platform demonstrates that maintenance of erect posture is an active process associated with numerous, invisible movements. Movement associated with maintenance of erect posture refers to changes in position of all body segments with regard to the vertical axis or to another segment. A system: Photogrammetrical Body Explorer (PBE) (i-Mond) meets these requirements and expectations (Figure 7).

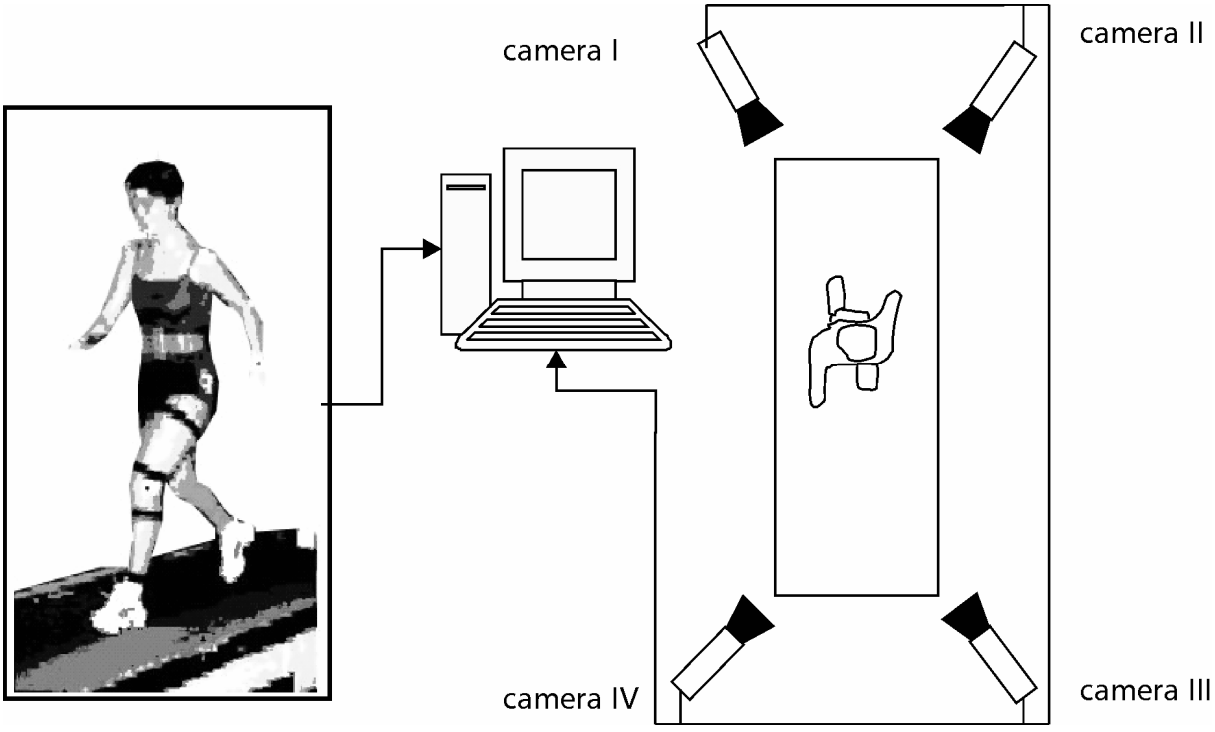

Figure 6

Measurement system for movement analysis based on digital video cameras-assisted registration

Figure 7

Photogrammetrical Body Explorer – a photogrammetric system manufactured by the company i-Mond, used for body positioning

PBE consists of devices for capturing pictures and of software for processing of the recorded pictures, calculation of spatial position of the measured points, constructing three-dimensional analyses based on these data, and for creating documentation in a from of plots and tables[2,3]. Two digital cameras with convergent axes at an angle enabling photographic registration of the whole human body (including its part reflected in the mirror also constituting a component of the system) serve to capture the pictures. Such configuration of patient position, cameras with coupled shutters, and the mirror allows simultaneous registration of measurement points located both on the front and back of the patient.

Clinical relevance

Systems basing on the Moiré's method fulfil the criteria of a relatively inexpensive and user-friendly device. They are used in screening studies for faulty posture in children as well as they allow evaluation of therapy progress. In fact, they do not assess the block of the body, but only a part of its surface and their relation to spatial studies is like a relation of bas-relief to sculpture. These methods belong to the category of the so-called superficial methods, where iso-lines, their number attribute, and shape provide information about the object[4,5,6].

The abilities to speak, stand, and walk are an inborn feature; yet, each of these activities requires learning. This statement is obvious regarding speech. A child starts to learn to speak at home and continues this process at school for many years. In case of standing and walking, each of us is a self-taught. Human gait is a very complex movement. Its quality depends on many factors; therefore, common observation of this phenomenon is superficial and poorly precise. Photogrammetric gait assessment enables evaluation of the quality of this movement and verification of the efficacy of treatment of the locomotor system. The systems, frequently integrated with dynamographic platforms and electromyography devices, provide broad study possibilities[7]. The price, time-consuming measurements, and a need for very large rooms for these studies effectively limit common use of this method.

PBE measures movement associated with sway or rotation of the marked segments. The measurement allows comparison of real position to the optimal one. The system of human body segments in motion remains in the field of forces of gravity. Maintained erect posture signifies that those forces are balanced. Quality of this balance is determined by spatial relationships of the studied segments. Measurement of all forces acting within the human body is unusually complicated and practically impossible. Models of distribution of forces by Stotte or Schulz used in biomechanics are considered a standard[8]. Does this mean that we loose at first approach? No, it doesn't. The nature does not calculate either. The nature compares. The PBE system enables us to compare conditions for a more or less optimal distribution of forces counteracting the gravity. As it was noticed[9,10],

parallel position of the shoulder line and the hips creates different conditions for maintenance of erect posture than their convergent position. This phenomenon, broadened by assessment of positions of the head, shoulders, hips, knees, and feet is evident in the PBE. The method has an application in diagnosis and treatment of chronic pain syndromes of the locomotor system, faulty posture, and osteoporosis. Based on these studies, parameters of an ideal body posture, associated with the type of reaction to the gravity forces, can also be defined.

Measurement errors

The Moiré's method is characterised by high precision of body surface reproduction. Asymmetry of the stripes generated by the system is usually the source of diagnostic information. This asymmetry primarily depends on the so-called baseline setting prepared by a person operating the system, who adjusts patient's pelvis into a position corresponding to the symmetry of its image displayed on the monitor screen. This "reinforcement" of posture constitutes already an interference with the measurement system. In the Moiré's method, markers of bone elements transformed onto body surface are used as well; hence remarks pertaining to marker signalling apply also to this type of testing. In the PBE system, points demarcated by the photogrammetric measurement are a transformation of skeletal elements onto body surface and are signalled with styrofoam pellets of 4-5 mm diameter. The accuracy of determining spatial coordinates of the signalled body points is high and is ±2-4 mm (depending on the distance of the photographed points from the cameras); it further results in a high accuracy of establishing angular values as a function of the lengths of segments that determine these angles. Angular relationships are more accurately calculated for longer segments; for example – non-horizontality of a 50 cm-long segment is determined (at an assumption of a 2 mm-error) with an accuracy of ±32°, whereas for a 10 cm-long segment – with an accuracy of ±1.14°. It should also be emphasised that accuracy of the system increases with increasing resolution of digital cameras. The above quoted accuracies refer to a system, where pictures are recorded by cameras of 1600 x 1200 pixel-resolution. Accuracy of photogrammetric systems determining coordinates of points in a three-dimensional space is usually high. It significantly exceeds resultant accuracy of the systems. Signalisation of anatomical points is an important source of markedly greater errors. When evaluating the measurement accuracy of various systems using markers, attention must be paid to the precision of their identification. Translocation of a marker in relation to an anatomical point during motion is another potential source of disturbance of measurement accuracy; this especially refers to systems assessing gait. Dependently on body region, this translocation can reach values of 15 mm and greater[11].

Summary

Experience of each of us favours general look as an indication of liking, force, and even health. Movement of the observed person also evokes our emotions. Both these features are an important carrier of information – information that is interpreted very subjectively. A need to objectively evaluate those experiences has existed for a long time. Photogrammetric studies correspond to these needs. Will they fulfil these expectations? Rehabilitation is a domain of medical sciences involved in issues associated with agility of motion of a human being; therefore, each test should evaluate this aspect. Scoliosis is not treated simply because of aesthetic reasons, but primarily because it compromises functions associated with living. This statement enforces our support for methods evaluating the movement. Both maintenance of erect posture and walking are associated with movement. Examining a movement, its parameters: force, mass, acceleration, velocity, energy, relativity must on one hand be measured and assessed, while on the other hand, conditions, in which this movement takes place must be evaluated. Coordination, cooperation, and optimisation are also very important for the quality of our motion. None of the presented methods comprise all aspects of movement. Comparison and judgement, which of the methods is better does not make any sense, because they are used to evaluate and diagnose different phenomena.

The seemingly great number of systems does not result in common application of remote measurement methods even there, where it is inevitable. In Poland, systems to evaluate scoliosis and, sometimes, to analyse gait, are used. What is the cause of this status? What requirements should be fulfilled to enable common use of a photogrammetric measurement system? Analysis of literature related to this topic, primarily including papers published in Archives of the International Society for Photogrammetry and Remote Sensing (ISPRS) during the period of time since the Congress in Hamburg (1980) until the Congress in Istanbul (2004), as well as internet publications, allow formulation of such requirements:

1) The measurement system must work there, where results of this measurement are used, that is in an outpatient clinic, or it should be mobile to enable conduction of preventive studies (e.g. detection of scoliosis in children at schools and kindergartens).

2) Capturing the pictures and performance of measurements must be a sufficiently fast process to provide results as early as during the visit at physician's office.
3) Results of the measurement should be presented in a comprehensible form, primarily for the physician, but also for the patient. They should be compared to normal values associated with a certain model or models defined by medical knowledge. Graphic representation of the results is preferred (pictures and plots).
4) The measurement should be simple enough to allow operation of the system by medical staff; its automatic features are especially desirable.
5) The system must be reliable, i.e. not requiring intervention of a photogrammetry specialist and resistant to possible mistakes of the operating person.

It should be realised that the success of a system in fact depends on whether it is useful in its particular application, whether it allows making correct medical diagnosis, whether it facilitates the process of therapy or is a valuable research tool.

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