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MACHINE VISION INVESTIGATE THE TRAJECTORY OF THE MOTION HUMAN BODY- REVIEW OF THE METHODS

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Abstract: The paper presents the analysis of possible applications of vision appliances in the measurements of motion trajectory of a limb (or all body) mainly in rehabilitation exercises. The paper also presents the analysis of techniques of carrying out measurements of trajectories of particular limbs including issues concerning: correct lighting of the studied object, marker selection as well as selection of image recording appliences. The paper also discusses the basic components of the vision systems designed for the limb motion registering as well as possible applications of the systems in the object (patient) identification. Exemplary applications of the systems for measurement of a trajectory of upper limbs motion have been also presented. The paper also discusses extensively the SFRT system designed for measuring and recording the motion range in human joints as well as a method of recording the results of measurements with the use of the SFRT technique depending on the kind of a joint.

1 Introduction

Machine vision systems usually enclose a camera and a machine analysing images, for example a computer with suitable software. All subsystems must be selected appropriately to needs of the determined application, in addition the problem of using the image processor in order to provide a proper time of acting and a suitable resolution of the system of imaging is crucial here [1], [3], [4], [7], [14].

Machine vision systems are used in non-invasive and non-impact measurements. These systems are used in the production as tools supporting the quality control, control of measurement of the geometry of the product, etc. in view to their character; they are also applied in medicine [1], [3], [8], [10-11], [15], [17], [23]. At present, the major attention is focused on registering the movement of a human body in form of a sequence of images [16], [18], [21], [23]. The main problem connected with the motion of a human figure is in estimating of the current configuration of the human silhouette. It is one of most difficult problems in the computer image processing, especially in view of a big space of research, diversity of human figures and environments of the observed individual. Works on observing the motion of the human body usually use simplified models [18],[24], homogenous environment [16] and properly selected clothes for the human body, in order to determine its characteristics. In the work [16] there has been created a system for observing movements of man, based on a geometric, three-dimensional model. The system was using images from three calibrate cameras. Experiments were realized in scenarios with black background. Although, there was used an improved molecular filter with the algorithm of the simulated event, still obtained periods of calculations were very long. Systems built from many cameras (so-called multi-cameras systems) [16], [20], [21] are usually used in applications observing movements of human individuals in order to obtain better results in the context of mutual hiding from view by human limbs and elements of the body. Applications of this type usually use probabilistic models of human silhouette [21] or its three-dimensional models [16], [18], [19], [24].

The application of a modern machine vision system might another method for analysing movements and modelling the motion and the figure of man.

The motion analysis encloses three parts: kinematics, kinesiological, electromyography and kinetics.

Kinesiological should be understood as a set of diagnostic procedures used in establishing the course of the rehabilitation with the physiotherapist; it constitutes a basis for preparing a plan of the therapy (long or short term) in order to resolve the problem of the patient.

It consists in gathering current information on patient's ailments, on his work environment, on sports he practices, on his household, in order to reduce its movement efficiently because the motion is the reason presented problems. The next part of the interview, enclosed in the procedure, consists in collecting information on the history of patients' diseases, injuries and operations he had during his life, or even some pieces of information not related with his current condition.

Kinesiological procedures enclose also studying muscles, valuing the mobility of joints and measurement of its level, examination of chosen functions for each area of the locomotive system – so called motional stereotypes.

Conclusions from Kinesiological can facilitate establishing suitable equipment for the rehabilitation. They can also help in getting additional information necessary in the further, additional diagnostics and methods of obtaining images, like RTG and USG.

From the point of view of technological solutions, modern systems for motion analysis can be classified into following groups [1],[5],[8], [10], [17]:

systems based on the digitization of images obtained from few video cameras (at least two),

systems based on the identification of markers placed on the body of the examined person:

- systems based on active markers,
- systems based on passive markers,
- ultrasonic systems.

All systems for motion analysis enclose also software for activation and preliminary processing of obtained data and software for preparing results of measurements and preparing reports, as well as specialist programs for creating biomechanical models.

All methods of measurement used in the objective, quantitative analysis of movement, can be divided into three groups [2], [4], [9], [15]:

- first group, which measure parameters of time and spacer (the tempo of walk, the frequency of steps, the length of steps, participation of individual phases in the cycle of walk or run, etc. In other words – the cycle of periodical motions).
- second group encloses kinematic methods that measure the trajectory of the motion in chosen points of the body, which is examined in a three dimensional space, as well as a (direct or indirect) measurement of angles in joints, determining the sense of direction of individual segments of the body towards oneself and measuring the speed and accelerations of one section of the body relative to the adjacent section.
- third group encloses kinetic methods measuring (directly or indirectly) forces and moments of forces that occur during the process of movement.

All systems for motion analysis can be integrated with other equipment and they can synchronize the register of data from all of them:

- systems for the surface electromyography,
- dynamographic platform,
- microswitches.

Systems based on active and passive markers also enable additional integration with one or two cameras recording the course of the examination, which are synchronized with vision data.

2 Systems for motion analysis criteria in clinical applications

Systems for motion analysis can be applied in ergonomic or sport studies, in film studios and in clinical examinations. Systems applicable in clinics should be characterized with following criteria [2], [9], [14], [25], [26]:

- a relatively big space of measurement that allows the patient to "fan out": kinematic and speed parameters stabilize only after the 2/3 of the step; the register should enclose the entire cycle of the left foot step forward and the right foot step forward; this means that the length of the measurement space should be : (3 x 65 cm = 2 m – "fan out" steps) + (2 x 1 m = 2 m – two cycles of walk) + (2 m – additional distance from cameras) = 6 m;
- small measuring vagueness (less than 1 mm),
- a relatively simple marker that requires not many markers (especially in case of small children), which will not make the cooperation with other systems difficult (for example for the dynamic electromyography),
- records made in c3d format,
- a relatively user friendly and simple software for activation and processing data with simultaneous provision of flexibility, which is necessary in scientific research,
- possibility of integrating and synchronizing the system with other measurement systems (microswitches, dynamographic platforms, dynamic electromyography systems) and integrating them in the software and c3d files.

Different systems, depending on their types, producer and model, have varied accuracy. More detailed information on the accuracy of different system is presented below.

The majority of systems for motion analysis using the digitalization of the video image in the course of three-dimension reconstruction obtain a measurement with a degree of inaccuracy equal 5.4 mm (± 2.7 mm) in the sagittal plain and 3.8 mm (± 1.9 mm) in the frontal plane and 6.0 mm (± 3.0 mm) in the transverse plane. This inaccuracy is not characteristic for all systems. For example, the Ariel APAS system has more inaccuracy, equal circa 11.6 mm [12], and the Dynas system reaches even up to 18.42 mm.

In case of the optoelectronic system VICON 370 the inaccuracy of measurement of the centre of the marker is determined on the level of 2 mm with the assumed distance of 500 mm between markers with the diameter of 25 mm. reducing the diameter of markers to 14 mm allows obtaining the accuracy of less than 1 mm, i.e. 0.98 mm. Lately, after the implementation of the new generation of MX cameras, and even T cameras, according to information of the producer, the inaccuracy of the measurement dropped significantly and now it reaches the scale of less than 0.05 mm.

Designed vision systems allow among other [9], [25], [26]:

- optical motion analysis of the limb, but also an optical motion analysis of any part of the body (limbs, palms, but also the spine),
- the result of the analysis is explicit and does not require additional processing and analyses,
- the system allows making examinations in conditions of illumination typical for medical rooms and rooms, in which the rehabilitation is being conducted,
- the designed system guarantees the possibility of diversifying markers overlapping each other, removing and correcting system errors, creating and deleting new points, changing names assigned to markers. Changes can be conducted in the 2-D vision and in the X-Y system of coordinates.

It is worth underlining that every producer of systems for motion analysis guarantees fundamental software for activating and preliminary processing data.

Defining software for activation and preliminary processing data in a determined vision system gives possibilities as follows [26]:

- it allows sizing the system (i.e. determining the position and orientation of cameras in view to the global system of coordinates) before the initiating the data collecting,
- simultaneous gathering vision data and analogical data,
- synchronization in time of all gathered data,
- creating a fundamental database, in which data from examinations is being collected.

In case of systems based on the digitalization of the video image, the software additionally allows automation of marking characteristic points of the patient's body in following action shots.

In case of marker systems, it allows supplementing gaps in trajectories of markers and filtering data.

Depending on the producer, further stages of the data is processing and analysis can be realized in different ways.

Some producers use the software from external companies, which make the further data processing, i.e. forming a model on basis of localizations of markers in the local system of coordinates, they calculate angles in individual joints and they send obtained data to the final report. The Visual 3D software, produced by C-Motion company is the most popular program. It is used among other by companies like Qualisys or Charnwood Dynamics.

Data collected with use of these systems for motion analysis constitute the basis for making biomechanical models.

Biomechanical models can have following purposes [1], [5], [8], [20]:

- estimating charges during motor tasks of different kind impossible for the direct measurement (like in joints),
- estimating charges of the body while acting of different powers and outside moments (collisions, injuries),
- estimating the disintegration of muscle forces during various motor tasks in the norm and in pathology,
- estimating the changes of length of muscles.

Most popular software programs are:

- Anybody (www.anybodytech.com),
- SIMM (Software for Interactive Musculoskeletal Modeling) (www.msculographics.com),
- OpenSim –Open Source (smtk.org) type of software.

It is known that the rehabilitation is aimed at giving back the lost ability to the patient, initiating actions for preventing the occurrence of such disability, as well as precipitating producing substitute compensating mechanisms – in case of morphological permanent damages.

The efficiency of rehabilitation for people with disabilities can be improved by the application of manipulators or rehabilitation robots (for therapy, physiotherapy). Therefore, the rehabilitation robotics is a domain that focuses on using manipulators and robots in the rehabilitation of people with disabilities.

The use of Internet enables the development of a new method of rehabilitation of disable people called telerehabilitation.

In order to establish the degree of the progress of illness, determining the degree of the malfunction of the pathologically changed limb, a range of measurement must be made. The measurement of movement in joints is made with special instruments called goniometers. In past years, a SFTR method is achieving popularity. It is a method of measuring particular movements in particular planes: Sagittal-S, Frontal-F, Transverse-T and Rotation-R and recording results. The use of this method aims at increasing the objectivism of measurement of ranges of motions. Movements in all joints are measured from the initial position – a so-called neutral zero, and all positions and movements are described in all of three dimensions mentioned before - SFTR [5].

Coupling the vision machine system with the SFTR method resulted with the occurrence of a new diagnostic, non-invasive, measuring method.

The Table 1.1.is illustrating an exemplary record of angle measurement for a human joint obtained with use of the SFTR method.

The record is coherent with requirements of ISOM (International Standard Orthopaedic Measurements) standards.

Table 1.1. Record of the SFTR system of measurements of angles in human joints in accordance with ISOM (International Standard Orthopaedic Measurements) standards – joints: cervical, thoracic, spine and the cingula of upper and lower limbs [5]

Joints	SYMBOL OF THE PLANE	Movements	Standard of ISOM
Of cervical spine	S	Extention-0-bend	40-0-40
	F	Side bend -0- Side bend Left right	45-0-45
	R	Rotation left – 0- rotation right	50-0-50
Of thoracic and lumbar spine	S	Extention-0-bend	30-0-85
	F	Side bend -0- side bend Left right	30-0-30
	R	Rotation left – 0- rotation right	45-0-45
Of the cingule of upper and lower limbs	S	Extention-0-bend	50-0-170
	F	abduction –0- adduction	170-0-0
	T	Extention Bend horisontally	30-0-135
	R	rotation – 0 – rotation inside outside	R(F0)* 60-0-70
		rotation – 0 – rotation	R(F90)
	R	outide inside	90-0-80

A correct assortment of the illumination is an important problem in creating the vision machine system. It is one of most important operation in the course of preparing the vision system for work. A proper illumination provides an image with correct parameters, which in turn guarantee the required functioning of the entire system. The illumination of the object often changes depending on extrinsic factors (movement of the sun, changing illumination) and, in consequences, causes problems in the correct functioning of the system. Therefore, very often an additional source of light, dedicated to the system and independent from external factors, is used in the examination. The choice of illumination is determined by many factors and at the end, for every system, this parameter is individually adjusted [29-30], [33].

Table 1.1,. 1.2, 1.3 and 1.4 presents record of the SFTR system of measurements of angles in human joints.

Table 1.2. Record of the SFTR system of measurements of angles in human joints in accordance with ISOM (International Standard Orthopaedic Measurements) standards – joints: elbow, prearm, radiocarpal, wrist, [5]

Joints	SYMBOL OF THE PLANE	Movements	Standard of ISOM
Elbow	S	Extention – 0 - bend	0-0-150
Prearm	R	Supination – 0 - pronation	90-0-80
	S	Extention-0-bend	50-0-60
Radiocarpal and wrist	F	abduction abduction radial -0- elbow	20-0-30

Table 1.3. Record of the SFTR system of measurements of angles in human joints in accordance with ISOM (International Standard Orthopaedic Measurements) standards – joints: carpal and metacarpal 1, metacarpophalangeal 1, metacarpophalangeal 2-4, proximal interphalangeal 2-4, distal interphalangeal 2-4 [5]

Joints	SYMBOL OF THE PLANE	Movements	Standard of ISOM
Carpal and metacarpal 1	VF	Extention-0-bend	30-0-15
	VS	abduction -0- adduction	40-0-0
	CR	lead-0-abduction	20-0-90
metacarpo phalangeal 1	S	Extention-0-bend	5-0-50
metacarpo phalangeal 2-4	S	Extention-0-bend	30-0-90
	F	abduction-0-adduction	Variable
metacarpo phalangeal 1	S	Extention-0-bend	15-0-05
proximal interphalangeal 2-4	S	Extention-0-bend	0-0-100
distal interphalangeal 2-4	S	extension -0- bend	0-0-80

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The explanation of symbols included in Tables 1.1., 1.2., 13. And 1.4 is as follow:

- S- sagital plane; F- frontal plane; T- transverse plane; R- rotation plane
- *R(F0) – means in this case that the external and internal rotation of the shoulder are measured in a situation, in which the joint is in the frontal plane, placed in the adduction - F0*. R(F90) – this record means that both rotations are examined in position of the shoulder abducted are 90°.
- **(S90) – means that during the examination of movements of the rotation in the hip joint the knee joint is bent to 90°.
- ***(S0) – means that during the examination of movements of the rotation in the hip joint the knee joint is erect.

Table 1.4. Record of the SFTR system of measurements of angles in human joints in accordance with ISOM (International Standard Orthopaedic Measurements) standards – joints: coxal, knee, crurotalar articulation and Chopart's joints[5]

Joints	SYMBOL OF THE PLANE	Movements	Standard of ISOM
Coxal	S	Extention-0-bend	15-0-125
	F	abduction –0-adduction	45-0-25 (
	R	rotation – 0 – rotation outside inside	S90)** 45-0-45
	R	Rotation -0- rotation outside inside	(S0)*** 45-0-40
Knee	S	Extention-0-bend	0-0-130
crurotalar articulation and Chopart's joint	S	Extention-0-bend	20-0-45
	R	Converting - 0 - turning away	20-0-40

A properly selected illumination must fulfil following requirements:

- maximum contrast between observed features,
- minimum contrast between features, which are not objects of the examination,
- minimum sensibility for changes in the process.

The kind of illuminated object is a very important factor that must also be considered in the course of establishing the type of applied illumination. The most common phenomena observed during the process of illuminating are: absorption of light, reflection, transmission, refraction (partial reflection), dispersion (e.g. rough surfaces) and emission [2], [5], [10], [14], [23], [30].

Cameras in the vision system are most often equipped with integrated illumination in form of LED diodes, placed around the objective. In most cases, this amount of light is sufficient for making a correct inspection. Diodes illuminate the object with impulses of light with the frequency programmed in the memory (light impulses of diodes are giving more lighting than in case of the constant illumination). However, situations in which one should apply the special lighting, adjusted suitably to occurring conditions, are happening. The most frequent mistake is that people do not use all possibilities of machine vision systems. The developed communication with most frequent protocols gives the possibility of large integration with the environment (drivers, implementation devices, etc.). For example: the combination of the system with the barcode reader or with the RFID system gives the possibility of checking the contents of the container (e.g. multi-packs with water) and its accordance with the label [6], [14], [28].

Sensors used in machine vision systems are also important elements.

Machine vision systems have a developed area of equipment and software; this gives them more potential for using them. Sensors gives input data (like results of measurements), unlike detectors that only inform whether the determined condition is fulfilled or not [6], [13-15], [20], [23].

Machine vision systems used in the quality control have many possibilities. The image obtained from a camera is preliminarily processed before the control itself starts.

Possibilities of some vision systems are following [6], [13-15], [23]:

- detection of the image (yes, no),
- summing up objects,
- comparing with the standard and determining the size of the discordance,
- dimensioning (often used in processes of cut, cutting, drilling, threading and other of this type),
- identification of the model in different plains and under different angles,
- monitoring colours (used among others in the food industry),
- identification of the object.
- Exemplary application of machine vision systems [4], [7], [14], [15], [22]:
- examining the correctness of making the intermediate product or the final product,
- identification of objects,
- recognizing,
- reading of 1D, 2D bar codes and ASCII signs,
- summing up objects,
- sizing and measuring,
- sorting.

3 Review of chosen methods of measuring the reach of joint mobility

3.1. Ranges of joints' movements

The correct range of movement of a joint is one of more important factors of the efficiency and the method of measuring it is one of basic methods of assessing the state of the motor organ and a measure of the result of rehabilitation activity. The measurement of the range of mobility in joints is realized with the use of specialist instruments called goniometers. They can be significantly diversified: starting from simple ones, based on the principle of a standard protractor, gravitational protractor, to complicated, electronic instruments, using the phenomenon of the change of the capacity of covers of the condenser depending on the location or change of the resistance of sphygmomanometers. Simple goniometers are sufficient for static measurements of passive ranges of movements in joints. However, when the angle position should be measured in a continuous way, it is necessary to use electronic goniometers. Such situation takes place in measurements of ranges in dynamic conditions, in conditions of motion [3], [14], [15], [27], [29], [32].

The measurement of ranges of movements is established to be relatively not objective. This assumption is connected with the great freedom of the position, in which the measurement is realized (differences can reach even circa 20% of value) or with a relatively big error between particular people conducing measurements. In last years, the SFTR method of measurement and record of results becomes popular, which aims at increasing the scale of objective assessment in the process of measuring the range of movements. Movements in all joints are measured from the neutral zero position and all positions and movements are described in three basic planes with use of the SFTR method [5], [29], [31].

3.2. Methods for measuring the range of mobility

Amongst many universally used methods of measuring the scope of limbs' mobility one should mention among others methods [29]:

- RTG method – a very accurate method, but because of the risk resulting from the radiation, it is not applied in everyday life,
- photographic - suitable for publishing and documentary destinations,
- trigonometrical - great error of measurement, impossibility while examining,
- spherometric measurement - for examining spheroid joints, is held on the surface of a sphere, results are being marked graphically on a cartographic net – lengthy,
- kinematic – is based on establishing temporary reallocations middle of the movement in ponds, difficult to do,
- perimetric - is coming from the method used in ophthalmology,
- outlining - for the application in duction of the wrist and fingers,
- planimetric - goniometry – measurement of the movement only in one plain, most universal in practice.

Conclusions

The developments of digital imaging as well as the new possibilities of digital image analysis allow us to apply these technologies for the analysis of human joints flexibility. Particularly interesting is the ability to accurate measurement of the progress achieved in rehabilitation and treatment of the patient. The currently proposed systems are complex and not too precise which results in discouragement of the medical community to use them. For this reason the development of a reliable and user-friendly method of measurement and analysis seems to be necessary.

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