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New scenarios in human trunk posture measurements for clinical applications

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Abstract— **It is well established how maintaining a correct body posture is absolutely fundamental to prevent skeleton and muscular pathologies. For instance the trunk's postures assumed in a typical working day for who spends many hours in front of a pc-screen, or the typical motion behaviour in the classroom routine for the pupils, can even lead to some body handicaps. Accordingly, it appears obvious how the exact evaluation of assumed postures during the possible daily activities is the starting point for the adoption of related prevention expedient or the application of subsequent medical treatments. On the basis of our experience, this paper deals with the common adopted systems for measuring human postures, especially related to the torso, suggesting a complete classification scheme, and imaging new possible future scenarios for clinical applications.**

Keywords- Trunk, bio kinematic, gait analysis systems.

I. Introduction

In spite of all the mentioned considerations in abstract, the common and consolidated technical methods for measurements of human postures and, more specifically, human kinematic can still be bulky, time consuming, expensive and can require skilled operators. We are thinking, for instance, to the optical based gait movement analysis systems which require high performance webcams with specific spatial allocations, sophisticated motion tracking software and an environment with adequate dimensions. Last but not least, the cost of one of this system can be of the order of tens or hundreds of thousands of Euros.

To overcome the previously detailed limitations of static and dynamic human posture measurement systems, in the latest years new technical methods have been developed and successfully adopted. These methods can, for the most part, still be considered in their experimental phase, but researchers are dedicating more and more efforts taking into great consideration the new interesting potentials that the new systems can offer. This paper intends to point out which new scenarios can be the more interesting ones in the "art" of measuring the human static and dynamic postures, but paying a particular attention on the human trunk motion analysis.

II. Classification

There are so many different human motion measurement systems that a classification can be helpful. So, in 2005 Wang suggested a possible schematization, based on position of the sensors and the sources [1]. Specifically:

Type A. Outside-In Systems: the sources are attached to the body, the sensors are somewhere else in the world.
Type B. Inside-Out Systems: the sensors are positioned on the body, the sources are somewhere else in the world.
Type C. Inside-In Systems: the sensors and sources are on the user's body.

Here we suggest to add the fourth possible category (see Fig. 1), i.e. the:

Type D. Outside-Out Systems: both sensors and sources are not (directly) placed on the user's body.

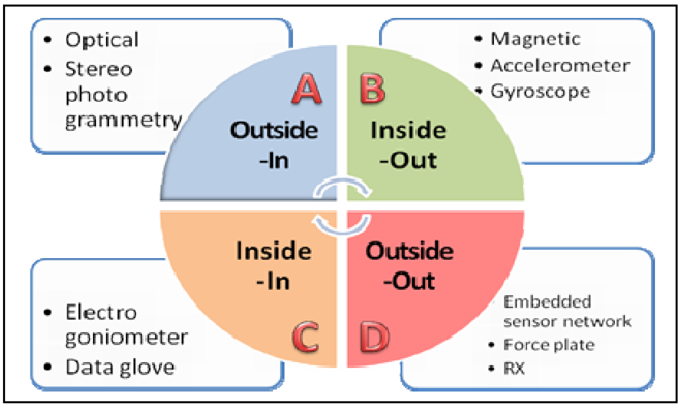

Figure 1. Schematization of body posture measurement systems

Let's furnish examples of each category.

Type A. Outside-In Systems

The most common motion tracking method which can be classified as "A" type (Outside-In) typically involves optical techniques (see OptiTrack @ www.naturalpoint.com/optitrack, Optotrak Certus @ www.ndigital.com as examples). Indeed the optical method has really old roots, since 1870 when E. J. Muybridge analyzed human and animal movements by means of a sequences of photographs (see Fig. 2). At the beginning the method was necessarily inaccurate, but nowadays the optical system has reached a really complete maturity.

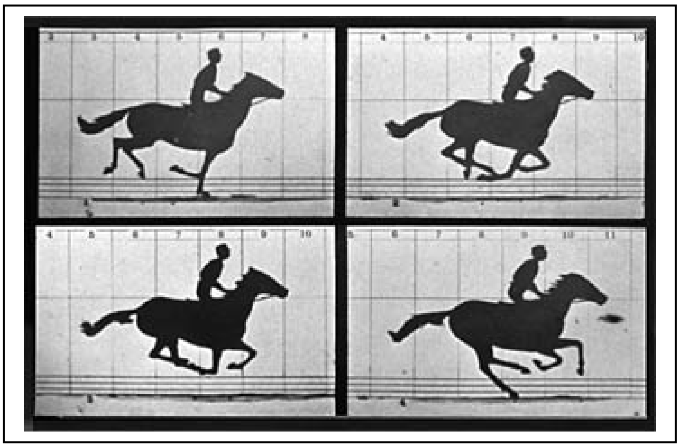

Figure 2. Muybridge's. The horse in motion

For the modern optical system developments the markers, which are the sources, are used strategically placed on the wearer's body parts which are to be tracked (most often on elbows, knees, wrists, ankles, and other joints, or specific points on the torso). Commercial complete suits exist (200,00÷300,00€) with embedded sensors already placed into the key body points to be monitored.

Cameras, which are the sensors, capture the wearer's movement, and the motion of those markers can be tracked and analyzed. An example of application can be found in the "Lord of the Rings" movie productions to track movements for the CGI "Gollum" character. The system's main advantages are that it can record very fast (each camera till 370÷500 fps) a tremendous amount of data, it is not intrusive, well-established in clinical practice and has a reliable measurement procedure. On the other end there are some consistent drawbacks, some of them previously detailed, and others d the markers can become obfuscated from the camera (a clear line of sight is always required between sensors and sources).

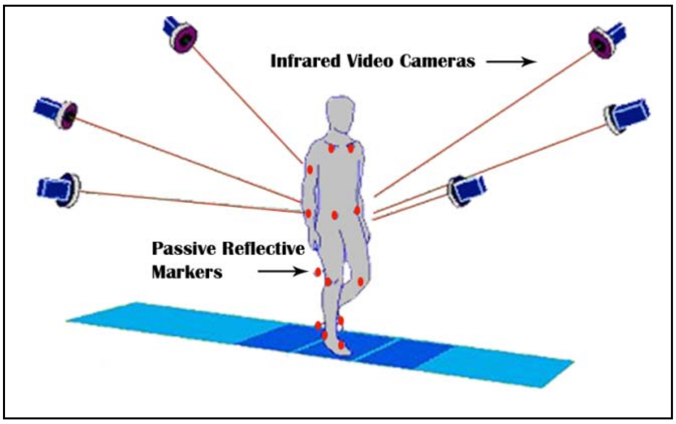

Figure 3. Optical based measuring system

So multiple cameras (6, 8, 12 till even 24) have to be used to (mostly) overcome the occlusion problem. The environment is another weakness point, because the system cannot be applied outside the restricted clinical space, but especially for the measure of trunk postures, the measure would be extended to daily activities. Cost is another major concern, proprietary systems can range in price, but a 6 camera system can be as expensive as 4500÷6000 Euros, a 12 camera system can be in the range of 25÷35 thousand Euros.

Type B. Inside-Out Systems

Systems of the "B" type are based on sensors directly placed on the user's body, which react to an external source. Magnetic systems, such as the 3D Space Fastrak (www.polhemus.com), fit into this category. The subject moves in the space of magnetic fields, the sources, established along three orthogonal axes and the sensors track by detecting the fields. The advantage of these systems is that they do not require a clear line of sight between sensors and sources, thus eliminating the occlusion problem typical of the optical methods. This is a meaningful advantage but other problems must be taken into account. Accuracy is an issue with this system because if any metal is present, the field can be even strongly affected, and the system latency can be as much as 0.1 secs. Electromagnetic tracking could be not advisable for patient with electrical implantable devices and prostheses and the overall system tends to be bulky.

In the same "B" type category there are some kind of "wearable sensors", generally inertial or mechanical devices. In the first case, the sensors commonly used are accelerometers and gyroscopes. These sensors, placed on a segment of the body, can provide information about acceleration, tilting angle relative to the gravity, and angular rate. Accelerometers measure proper acceleration and, in absence of movement, the gravitational acceleration if the axis of the sensor are not orthogonal to the force of gravity. In this way it can be measured the inclination of a body segment. The velocity can be obtained as the integral of acceleration and the displacement as the integral of velocity. However, this procedure may be affected by measurement errors and by important drifts. The employment of accelerometers in biomechanical analysis has proved to be promising and there are a lot of clinical applications in literature. By placing accelerometers on two or more segments of the body (e.g. trunk, thigh or shank) standing, sitting, lying and locomotion can be recognized [2]. A bi-axial accelerometer, attached at the last thoracic vertebra, T12, level of the back, can be used for determining the time spent in assuming different static trunk posture during a typical working day [3].

Gyroscope can allow absolute measures of angular velocity of a segment of the body with respect to an axis. Rotation angles can be obtained as the integral of angular velocity. Also in this case, the measure may be affected by drift and, furthermore, gyroscopes have some disadvantages like the price and the sensitivity to shock.

With the aim of compensating the drift of these inertial sensors, integrated systems, with both accelerometers and gyroscopes and sometime with magnetometers, have been developed. Inertial Measurement Units (IMUs) are been obtained which can be utilized as portable motion analysis system and there are many example in the literature about their clinical applications [4, 5].

Type C. Inside-In Systems

Systems of the "C" type are particularly used to track body part movements and/or relative movements between specific parts of the body, having no knowledge of the 3D world the user is in. They can be intrusive on the subject and may restrict his/her movements. Such systems is for sensors and sources which are for the most part realized within the same device and are placed directly on the body segment to be measured or even sewed inside the user's garment. So the interest in the Inside-In Systems is growing since they allow to monitor the natural motion of the body during daily activities in domestic environments. The design and implementation of sensors that are minimally obtrusive, have low-power consumption, and that can be attached to the body or can be part of clothes, with the employ of wireless technology, allows to obtain data over an extended period of time and without significant discomfort. Furthermore, this advantages permit to redirect clinical assessment from the dedicated laboratory to a more real-life setting such as the home. So clinicians may obtain complementary data respect those obtained in clinical environment, and would benefit from both data gathered during the performance of activities of daily living and data recorded in the clinical setting under controlled conditions [6].

In the latest years the so called "bend sensors" are more and more applied. These are mostly piezoelectric based devices which are placed directly on the human joint or trunk part under measure. An example is the "data glove" [7] capable to measure all the degree of freedom of the human hand. But the same sensors can be applied for the human trunk posture measurements as our research group is carrying on and showed in Fig. 4.

Figure 4. Bend sensors are applied on garments to measure trunk postures. A 3D avatar furnishes a visual feedback.

Type D. Outside-Out Systems

Systems of the "D" type (we introduced here) consider both sensors and sources not directly placed on the user's body but in the surrounding world. Let's consider, for instance, the radiology. Nowadays it is practically used for trunk movement and posture analysis. It presents the great advantage of a very high measurement accuracy since it shows directly what happens to the joints. Obviously, on the other end, it can be hazardous, for repeated X-ray exposures and needs highly skilled operators and special dedicated environment. We cannot affirm that in the radiology, sensors and sources are placed on the user's body. In the same way the new Wireless Embedded Sensor Networks cannot fit in the three classifications provided by Wang. These networks consists of sensors embedded in object such as an armchair (see Fig. 5) or a mattress, which detect the human postures and, on the basis of the recorded measures, self modify their shape to fit themselves to the user (even taking into account the environment changes). Force plates measure the ground reaction forces generated by a body standing on or moving across them, to quantify balance, gait and other parameters of biomechanics. These plates hold the sensors which react to an external force (the gravity), so can be considered type "D" Systems.

Figure 5. An armchair incorporating sensors.

Clearly each of these systems has its advantages and disadvantages so no perfect system exists. A possibility can be do adopt multiple systems, adding the benefit of one to the accuracy of another. A hybrid system combining sensors directly on the user's body with an optical marking system, for instance, might increase accuracy for very precise measures. An interesting hybrid example is the so called MoCap System (Motion Capture), which records the human body movements so to be useful utilized in 3D avatar representation via personal computers. It works thanks to three different technologies having respectively optic, magnetic and electromechanic basis. Another example is the Gypsy 7 Torso Motion Capture System (www.metamotion.com), an electro-mechanical system consisting of an exoskeleton made of lightweight aluminium rods that follow the motion of the user's bones. Potentiometers at the joints change their resistance with the angular rotation of the rods. A gyroscope is used to calculate the bearing (rotational direction) of the hips.

III. METHODS

Our purpose is here to understand which are the most important and/or appealing requirements a measuring system must satisfy, to discover which possible new scenarios will be opened in the next future. To this aim we submitted a detailed form to 24 people actually or potentially involved with the utilization of human trunk motion and measurement analysis systems. In particular we interviewed 4 groups of people divided into 6 clinicians (3 spine surgeons and 3 orthopedics), 8 bioengineers, 4 orthopaedic technicians, 6 patients with light/heavy trunk's injuries. The form is divided into four sections: the first "overall" concerns general considerations, the second "data" and the third "measure" are devoted to acquisition and analysis, the last "patients" mostly concerns the user's point of view. Each row of the form reports a question beginning with "The importance to have …?" to which each of the 16 people are asked to reply with a weight from zero (no importance at all) to 5 (maximum value). Table 1 reports the results, where the last four columns summarize the average values obtained from the 4 groups of people.

TABLE I. FORM SUBMITTED TO 24 PEOPLE INVOLVED IN TRUNK POSTURE MEASUREMENTS. COLUMN "A" IS FOR CLINICIANS, "B" FOR BIOENGINEERINGS, "C" FOR ORTHOPEDIC TECHNICIANS, "D" FOR PATIENTS TABLE TYPE STYLES

OVERALL		A	B	C	D
O1	Low cost	4	3.5	3.25	2.33
O2	High portability	4.5	4.25	4.5	4.67
O3	Good lightness	3.83	3.88	4.75	4.33
O4	Short time to assess the measurement	3.67	4.13	4	3.83
O5	Easy to use	3.5	4	4.25	3.83
O6	Skilled operators, dedicated environ.	4.33	3.13	4	3.5
O7	Systems robustness	4.33	4.63	4.75	4
O8	Short calibration time	3.5	4	4.5	4
O9	Low power consumption	3.83	2.88	2.75	2.33
O10	Consolidated technology	3.83	3.25	3.25	2.5
O11	Self consistency	2.67	2.25	2	1
O12	Indoor/outdoor usage	3.83	4.63	3.5	3.5

DATA		A	B	C	D
D1	Low data analysis complexity / Processing time	2.67	1.88	2.5	1.33
D2	Low number of key measurement points	3.33	3.75	2.75	3.67
D3	Real time / Negligible transient time	3.83	4.63	3.5	2.33
D4	High frequency sample	3.67	3.38	3	2.17
D5	No ambiguity	4	4.88	4.25	1.83

MEASURE		A	B	C	D
M1	Repeatability / reversibility	4.83	4.13	3.75	3
M2	Accuracy	4.83	4.38	3.75	3.5
M3	Long term	4	4	3.75	3
M4	No sensitivity to shock	4	4	4	2.5
M5	No influence of environment	4.17	4.63	4.25	3.33
M6	Autonomy	3.33	3.25	4.5	3.83
M7	Immunity to noise / disturb / drift / shifts	4.67	4.25	2.75	2.5
M8	Indirect measure	3.17	2.5	2	1.5
M9	Independence from the environ.	4.33	4.63	4.5	4.17
M10	No occlusion problems	3.67	3.75	3.5	2.17
M11	Limited to 2D or for 3D measures	4.5	4.25	3	1.33

PATIENT		A	B	C	D
P1	No mechanical constrains	4.67	4.38	3.75	4.17
P2	Non intrusive	4.67	4	3.75	4.5
P3	For normal day activities	4.67	4.63	3.75	4.33
P4	Unhazardous / uninvasive	4.83	5	5	4.83
P5	Low weight / bulkiness	3.83	3.63	4	4.33
P6	Large space for movements	4.83	3.5	3.5	4
P7	Subject's acceptance	4.67	4.13	4.25	4.67
P8	Self adoption	3.5	3.38	3.25	4.17

To give a meaning to the form, we added each row values obtaining 12+5+11+8 = 36 numeric results, and empirically (only based on our experience) assigned a positive result only to the row sum greater than 16 (being 20 the maximum rate). In this way we can say that the type "A" Outside-In Systems have a low consideration, the type "B" Inside-Out Systems have been positively considered with except the magnetic based solution, the type "C" Inside-In Systems have a good consideration and finally the type "D" Outside-Out Systems have a great consideration if we leave out the radiology application. So the results of our test indicates that the systems to which people look generally with more attention are hybrid, collecting the most interesting features mainly of the type "D", and partially of the types "B" and "C" Systems. The type "A" has its importance, but restricted for applications which needs robustness and without any kind of mechanical constrains.

IV. FUTURE SCENARIOS

Relating to our experiences, it makes sense that the measuring system has not to limit its capabilities to furnish to the operator "only" reliable measurements. We suggest that it must be completed with "added values". As a starting point it would be important to define a standardization for the measurement protocols. Nowadays each system has got its own procedure for the measure of the human trunk and, generally, of the human body. All teams involved in body tracking adopt procedure strictly related to proprietary protocols for commercial systems or proceed on the basis of their particular experience for self realized systems or modified ones. So it can be hard for different research groups to share their experiences and ideas. Even the obtained measure can be difficult to compare and, over all, to validate among research groups if the results are reported on the basis of different protocols. We encountered the same problem for the Brain Computer Interface Systems, which is another of our research fileds and for which we suggested to adopt the UML (Unified Modeling Language) as universal language which allows to define a protocol for method and timetable [8].

Another key element we want to underline is the data "usability". Once data have been acquired it becomes fundamental to count on both a correct analytical tool and a proper representation. For a surgeon, for instance, it can make the difference to literally "see" each movement of the trunk's patient in re-play mode from any possible point of view. So we are thinking to overcome the present possibilities as the Arena graphic tool by OptiTrack or the Vicon (www.vicon.com) or the IGS-190 Technology (www.metamotion.com) applications offer, but looking for a possible future scenario of a hologram or stereogram that can report patient's motion via avatar in a real 3D space. This is what already happen in other fields as, for instance, the edutainment one (see Fig. 6).

Figure 6. Users donning special glasses see holograms of “floating planets” in the room (Courtesy by PFM Multimedia Company)

We suggest also that the measurement system can overcome the usual laboratory as a hospital (for rehabilitation purposes) or a movie set (for animating a character) can be. We believe that the treated systems can be usefully adopted, for instance, in psychology e psychiatry ambulatories since the body kinematic can furnish an important evaluation key for the emotional reaction a patient can present to several events. A further application based on body posture measure evaluations can furnish a body mapping giving to designers a tool for realizing more ergonomic stuff in fields like furnishings or automotives.

CONCLUSIONS

Human movement analysis is not really a new science. Let’s think that Giovanni Borelli is credited as being the first to make dynamic calculations of human movement even in the Renaissance period. But this science is necessarily based on systems capable to reveal human body kinematics. This paper furnishes a rapid overview of these systems, their classification, their advantages/disadvantages, but intends also to enlarge the commonly used classification, to indicate the need of a standardization, to suggest a universal language for protocols including time scheduling and to look forward to future possibilities and novel applications of human body kinematic measure.

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REFERENCES

[1] Wang, Yifei, 2005. Human movement tracking using a wearable wireless sensor network. Master Thesis. Iowa State University. Ames, Iowa.

[2] Aminian K., Robert Ph., Buchser E.E., Rutschmann B., Hayoz D., Depairon M., . Physical activity monitoring based on accelerometry: validation and comparison with video observation. Medical and Biological Engineering and Computing 1999; 37, 304–308.

[3] Wong K. CH, Lee R. YW, Yeung S. S,. The association between back pain and trunk posture of workers in a special school for severe handicaps. BMC Musculoskeletal Disorders 2009, 10:43.

[4] Goodvin C., Park E.J., Huang K., Sakaki K.,. Development of a real-time three-dimensional spinal motion measurement system for clinical practice. Medical and Biological Engineering and Computing 2006; 44:1061-1075.

[5] Wong W.Y., Wong M.S., . Trunk posture monitoring with inertial sensors, Eur Spine J. 2008; 17:743-753.

[6] Bonato P., . Advances in wearable technology and applications in physical medicine and rehabilitation. Journal of NeuroEngineering and Rehabilitation 2005, 2:2.

[7] Saggio G., Bocchetti S., Pinto C. A., Orengo G., Giannini F., . A novel application method for wearable bend sensors, ISABEL2009, 2nd International Symposium on Applied Sciences in Biomedical and Communication Technologies. Bratislava, Slovak Republic, November 24-27, 2009, pp. 1–3.

[8] Quitadamo L.R., Abbafati M., Saggio G., Marciani M.G., Cardarilli G.C., Bianchi L.,. A UML model for the description of different BCI systems. 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS 2008), August 20-24 2008, Vancouver (Canada), pp. 1363-1366.