PORTABLE/WEARABLE COMPLEX MECHATRONIC SYSTEMS FOR DETERMINING THE ANTHROPOMETRIC PARAMETERS NECESSARY IN THE ANALYSIS OF HUMAN BIOMECHANICS AND FOR POSTURAL CORRECTIONS

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Abstract - The paper presents a set of complex portable/wearable mechatronic systems, which allow both the determination of the anthropometric parameters necessary in the analysis of human biomechanics, as well as the realization of postural corrections, thus contributing to the rehabilitation and rapid integration into society of human patients.

Keywords Anthropometric parameters, Analysis of human biomechanics, Postural correction.

1. Introduction

The correctness of the biomechanics of human movement is influenced by the level of neuromuscular control and mechanical stability of the joints involved in the movement. Mechanical stability is ensured by the anatomical elements (bones, ligaments and muscles) that compose musculoskeletal system. Damage to any component element of the joint leads to changes in joint stability. In the case of structural damage to a joint (in the case of an anatomical injury), the functional recovery of the joint cannot be achieved only through orthopedic correction, but must be completed with exercises that stimulate the development of the neuromuscular system. In the case of irreversible alteration of neuromuscular control, compensatory functional stability must be ensured. These exercises have the role of increasing the functional performance of the joint and are based on activating the muscles that serve the affected joint. In general, such exercises are grouped in the form of a recovery plan/program.

The instrumentation used in anthropometric measurements to assess body size, to assess body composition and to estimate the amplitude of joint movements is very varied: taliometer, anthropometric ruler, anthropometric compass, metric tape, Harpenden anthropometer, medical weighing, plicometer, adipometer, goniometer.

Postural analysis equipment is also very diverse. There are 11 types of technologies, namely: force plate, photography, checkers, inclinometers and tape, 3D X-ray analysis, sensors, electromyography, kinect, magnetic resonance imaging, 4D computed tomography and infrared sampling.

A patient for his locomotor recovery has at his disposal a wide variety of devices, made with a varied range of facilities and having different performances.

As far as postural correction systems are concerned, the existing devices on the market have the disadvantage that the monitoring only addresses a limited portion of the user's spine, usually the thoraco-cervical or the lumbar area. However, there are also devices that allow the monitoring of the entire spine, but which do not take into account the position of the shoulders, this aspect being very important since postural changes can also be generated by incorrect positioning of the shoulders.

The concern to develop wearable/portable mechatronic systems based on the concept of WBT (web-based training), which ensures a remote interaction between patient and specialist even during medical investigations related to the analysis of the biomechanics of the patient's movement, as well as during the patient's recovery program, is a niche development direction of these devices.

Because most of these devices should be wearable/portable, a number of studies have indeed investigated the usability of wearable sensors to support their implementation during diverse applications [1–7], which have principally involved MEMS technology as an external device, both for medical investigations and for the recovery program.

Determination of the anthropometric parameters, necessary in the analysis of human biomechanics, and realization of postural corrections can be achieved easily with the help of the complex system that is the subject of this paper. One portable mechatronic subsystem and one wearable mechatronic system will be presented within the paper, these being brought together in a complex integrative mechatronic system with a major role in the programs of functional recovery of the Musculo-skeletal system, in the field of physical and sports medicine.

The solutions for the realization of the component mechatronic systems, as well as the functions for which they are designed, are innovative. The systems are designed in such a way that they can operate both independently and in an integrative assembly.

Also, the mechatronic integrator system is designed based on the web-based training (WBT) concept, by creating specialized software modules aimed at an easy interaction between the direct user (patient/athlete) and the specialist (doctor/coach).

By integrating the individual functions of the two mechatronic systems, the specialist will be able to perform an analysis of the biomechanics of the patient/athlete's movement and according to this he will determine the type of correction needed or evaluate the progress of the human subject.

The correct use of all individual functions of the proposed integrative system contributes to promoting a higher state of health and increasing the quality of human life.

By integrating the individual functions of the two mechatronic systems, the following results are pursued:

- With the first complex portable mechatronic system, the medical recovery specialist will be able to determine the preliminary anthropometric parameters, later used in the analysis of the biomechanics of the patient's movement. This mechatronic system for determining anthropometric parameters will be able to be used together with other auxiliary devices to perform complex movement analysis sessions, which will result in reports with anthropometric parameters specific to the analyzed patient. These reports, together with the patient's previous medical history, will lead to customized recovery/training schemes for the anthropometric and biomechanical characteristics specific to each patient/athlete. This type of movement analysis and reporting is also the benchmark against which the progress of the human subject will be assessed.

- The second mechatronic system will be designed as a wearable system that will be made available to the patient in order that, using this device, the person in question corrects the posture of the spine. The wearable device will notice and signal to the carrier patient the wrong postures of the spine, postural deviations from the standard values.

The diagram of the functions of the complex mechatronic system is shown in Fig. 1. The two functions that are implemented are presented, namely:

• determination of the anthropometric parameters necessary in the analysis of human biomechanics

• postural correction.

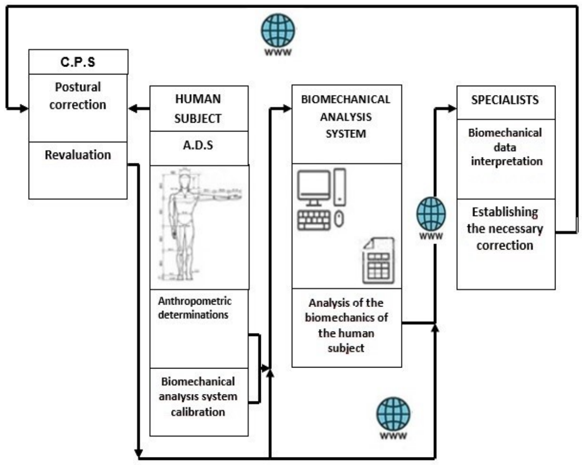


Figure 1: Diagram of the functions of the integrating mechatronic system

2. Complex Mechatronic System for Determining Anthropometric Parameters and Movement Analysis

An anthropometric analysis session in the field of physical medicine and rehabilitation includes measurements of body dimensions, joint mobility, structure and body composition of the patient / athlete.

Body size measurements are made according to certain anthropometric benchmarks.

Anthropometric landmarks [8] [9] are points/areas of interest positioned on the skin or bone level, identifiable or not from a physical point of view, generally located at the intersection of certain anatomical elements or determined by convex or concave bone areas.

Anthropometry is based on a series of principles and is expressed through parameters and indices. The parameters represent the values resulting from the measurements, while the indices represent a form of expression of the various ratios between the anthropometric parameters, according to which determinations, estimates and respectively predictions can be made regarding the state of health of the individual.

The most common measurements in the field of anthropometry are divided as follows [10]:

a) direct - these are divided into: general (height, weight, surface and total volume) or detailed (sitting vs. standing height, shoulder and hip width, arm/leg length and neck circumference, etc.);

b) indirect - those related to estimating the composition of certain anatomical structures - body fat percentage, skin thickness, muscle density and water content.

Usually, in a specialized medical office, anthropometric measurements are performed with various instruments (see Table 1). For this reason, the measurement precisions of the main anatomical segments are different, depending on the precision of each one instrument, which represents a major disadvantage in the evaluation of a patient.

Table 1. Table with the instrumentation used in anthropometric measurements for the assessment of body size, for the assessment of body composition and for the estimation of the amplitude of joint movements

Parameter	**Measuring instruments**
Body height.	Taliometer
Bust height	Taliometer Anthropometric ruler
-Antero-posterior diameter of the head Thoracic diameter Biacromial diameter . Transverse thoracic diameter Antero-posterior thoracic diameter	Anthropometric compass
Head circumference Neck circumference Chest circumference Abdominal circumference The perimeters of the upper and lower limbs Arm span Lower limb length	Metric tape
Shoulder width Upper limb length Arm length Forearm length Hand length Thigh length Calf length The length of the foot	Metric tape Harpenden anthropometer
Weight	Medical weighing
Skinfold thickness	Fold caliper Plicometer Anthropometric compass Adipometer
Amplitude of motion	Goniometer

The function of determining the anthropometric parameters of a patient is absolutely necessary in the calibration stage of human biomechanics analysis systems and will contribute to the scaling with a high degree of precision, by the proposed system, of the human subject under analysis. The more precise this scaling is, the more errors generated by the biomechanical movement analysis system can be reduced.

The complex mechatronic system that is presented in this paper will perform anthropometric determinations in three ways (see figure 2):

- using a mechatronic system with linear axes of movement connected to a system of 7 IR laser transducers SKU_SEN0366, system designed within INCDMTM, with the function of performing preliminary anthropometric measurements;

- completion of anthropometric measurements, by using the acquisition and processing of images of the human subject's body from a video camera;

- for the augmentation of the anthropometric analysis, the inertial motion analysis system will be used, which can deliver numerical data related to the angles and accelerations of the segments of the human body. Any data acquisition session with this equipment must be preceded by a hardware/software calibration of the equipment. This calibration will be done with the previously described mechatronic system.

The mixed video-mechantronic system will have two important characteristics: speed in obtaining some anthropometric parameters (body segments) conferred by the video system and the high measurement precision of a mechanical system.

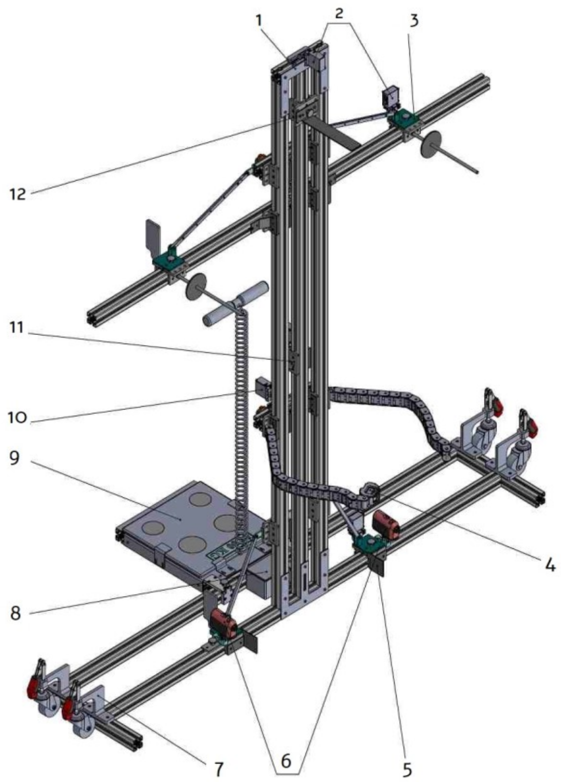


Figure 2: Mechatronic system for determining the anthropometric parameters

The results of the measurements will be recorded in tables, these tables will be transmitted in their entirety to the biomechanical analysis system, for the purpose of archiving and processing them. Data interpretation will be done by filtering them according to criteria established by specialists.

The calibration system designed to meet all the requirements listed above is composed of the following sub-assemblies and basic elements:

a) the support sub-assembly 1- represents the structure on which the other sub-assemblies will be located and has the role of supporting and giving stability to the calibration system. A circumference measurement subassembly 4, which also includes a IR laser transducer 10, can move vertically on this stand 1. Three sub-assemblies, 2, 11 and 12, of IR laser transducers SKU_SEN0366 are mounted on it. At its base, the displacement sub-assembly 7 and the medical weighing 9 are mounted.

b) lower measuring/locking sub-assembly 5- has the role of allowing the user to establish and maintain the distance between the heels. One sub-assembly of IR laser transducer SKU_SEN0366 is mounted on it.

c) the upper measuring/locking sub-assembly 3 - has the role of enabling the establishment and maintain the distance between the user's shoulders, as well as the distance from the ground to the tangent with his armpits. Two sub-assemblies 2 of IR laser transducers SKU_SEN0366 is mounted on it.

d) the steering sub-assembly 6 - has the role of indicating the direction and establishing the limits of the corridor on which the user must move, in such a way that there are no deviations from the route imposed during calibration.

Accurate anthropometric measurements performed with this system generate a set of main measurements of the human subject (height, arm span, bust circumference, hip circumference, leg length), which is later used for the calibration operation of the optoelectronic subassembly used in the mechatronic system presented above.

With this optoelectronic sub-assembly, the set of anthropometric measurements of the human subject required for motion analysis is completed.

Also, this optoelectronic system can be used for remote monitoring of the patient's recovery exercises.

This optoelectronic system is composed:

- Intel RealSense D435 Web Camera, which is equipped with a pair of depth sensors, an RGB sensor and an infrared projector, and is connected via USB 3.0 Type-C;
- adjustable tripod for mounting the web camera;
- laptop DELL Vostro 15 3000;
- operating software UBUNTU version 18.04.6 LTS, OpenCV package version 4.7.0, Mediapipe, Python version 3.10.5.

Software application that uses the video camera will be oriented in two directions:

a) The use of the video camera for anthropometric determinations complementary to those carried out with the mechatronic system of anthropometric measurements. In this case, the patient/athlete seated in the mechatronic system for anthropometric determinations, with the legs and armpits locked in the correct position for taking the measurements. The video camera must capture an integral image of the patient/athlete's body, be perpendicular to the patient's frontal plane and have the optical axis in the patient's sagittal plane.

The software application is written with MediaPipe Pose [11], which is a high-fidelity body pose tracking solution created by Google that renders 33 3D landmarks and a full-body background segmentation mask from RGB-encoded image frames (see Fig. 3). MediaPipe Solutions is part of the open source MediaPipe project, which provides a suite of libraries and tools to rapidly apply artificial intelligence (AI) and machine learning (ML) techniques to software applications. MediaPipe generates real-time detection solutions using digital images of the human body. These images can be obtained by capturing them in real time from a video camera or by extracting images from image files using the OpenCV software package[12].

With this application, the anthropometric dimensions of interest will be extracted from the skeletonized human body image, which will later be used in the calibration operation of the XSens MVN inertial motion analysis system.

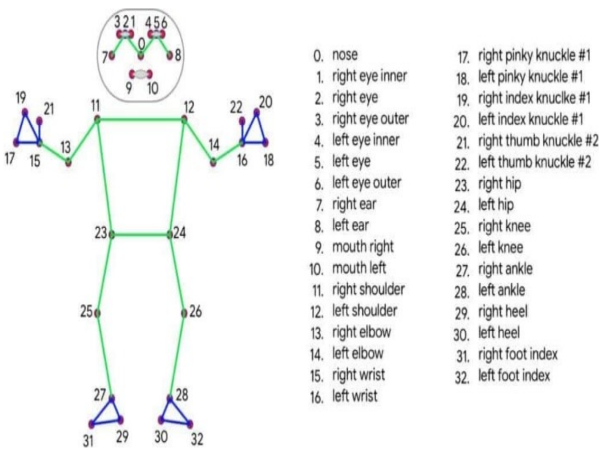


Figure 3: The endpoints detected by MediaPipe

Desktop software application determines the dimensions of the upper and lower limbs as well as the total height of the analyzed person.

The software application has been rewritten to function as a WEB application. Django was chosen as the framework for the Web server. The image is taken from the video camera physically attached to the computer on which the software application is installed.

The following functions have been implemented in the software:

- color image display
- gray image display
- black / white image display
- image frame freeze
- detecting the presence of the human subject's face in the image
- detection of body segments
- palm fingers detection
- detection of arm flexion / extension movements

A minimal human body segment identification and visualization software application written using the MediaPipe Pose library is shown below:

```
importcv2
importmediapipeasmp
## estimator inițial de postură
mp_drawing = mp.solutions.drawing_utils
mp_pose = mp.solutions.pose
pose =
mp_pose.Pose(min_detection_confidence=0.5,
min_tracking_confidence=0.5)
cap = cv2.VideoCapture(0)
while cap.isOpened():
# citire cadru de la camera video
_, frame = cap.read()
try:
# convesia imaginii în format RGB
    frame_rgb = cv2.cvtColor(frame,
cv2.COLOR_BGR2RGB)
# procesarea cadrului de inagine
    pose_results = pose.process(frame_rgb)
# desenarea scheletului obținut prin conectarea
punctelor de referință
    mp_drawing.draw_landmarks(frame,
pose_results.pose_landmarks,
mp_pose.POSE_CONNECTIONS)
# afișarea imaginii
    cv2.imshow('Output', frame)
except:
break
if cv2.waitKey(1)==ord('q'):
break
cap.release()
cv2.destroyAllWindows()
```

An example of determining body segments is shown in Fig. 4.

Figure 4: Human posture monitoring software application

b) The use of the video camera in the training/medical recovery sessions, for the remote monitoring of the correctness of the movements performed by the athlete/patient. In this case, the use of the video camera under specific conditions allows the creation of an .avi file during the training/medical recovery session. Films obtained during these movement sessions are later analyzed frame by frame, in order to identify the coordinates of the points of interest (shoulder, elbow and wrist in the case of the upper limb, respectively hip, knee and ankle in the case of the lower limb) necessary for the calculation articular angle.

The specialist will be able to perform an analysis of the biomechanics of his movement and based on this he will evaluate the progress of the human subject.

The same precision measurements are the most important input data for the hardware sub-assembly - MVN Link [13], of the XSens MVN inertial motion analysis system (fig.5), whose signals are processed by means of advanced processing algorithms and transferred to biomechanical models, resulting in movement information regarding the analyzed human subject, namely joint angles, kinematics of body segments, global position of body segments, center of mass of the body, data from sensors.

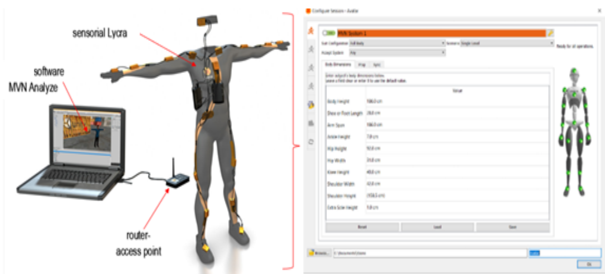


Figure 5: XSens MVN inertial motion analysis system

The software of the inertial motion analysis system transforms, in real time, the information received from the sensory network of MEMS into digital images, each movement of the human subject being represented by means of the virtual mannequin, allowing at the same time the display in the form of graphs of all elements of interest, within the analysis. (see Fig. 6).

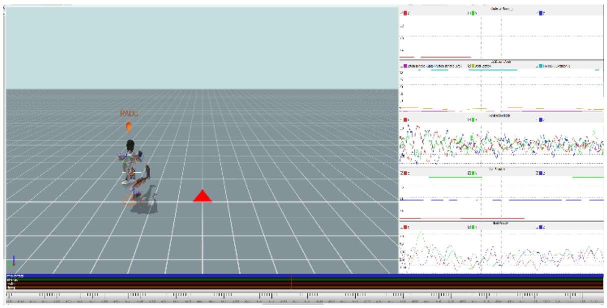


Figure 6: Representation of the graphical interface of the MVN Analyze software during an analysis session

3. Wearable Mechatronic device for Postural Correction

Correct body posture is a sign of psychophysical balance of the individual [14].

Postural deficiency treatment aims to reduce muscle tension and pain associated with incorrect body position. By changing daily habits and using proper exercises and techniques for stretching and muscle relaxation, tension and pain can be significantly reduced. In addition, the treatment of postural deficiency aims to increase the flexibility and mobility of the body. Postural deficiency treatment can also help prevent health problems associated with incorrect body position. By eliminating stress and pressure on muscles, joints and intervertebral discs, chronic problems such as back pain or herniated discs can be prevented. In addition, treatment of postural deficiency can improve posture and physical appearance of the body. A correct posture can lead to an increase in the quality of life and even self-esteem.

A wearable mechatronic device will be presented, used to maintain a correct human posture from the point of view of the physiological curves of the spine, as well as from the point of view of the positions of its shoulders.

This wearable mechatronic device is made in an innovative way and is the subject of a European patent EP3760170 entitled DEVICE FOR REAL-TIME MONITORING AND ACTIVE POSTURAL AUTOCORRECTION.

The main purpose of this wearable device is to allow the user to fulfill as correctly as possible the requirements of daily activities regarding the posture that must be achieved/maintained during the execution of movements of bending/straightening the trunk and lifting some objects.

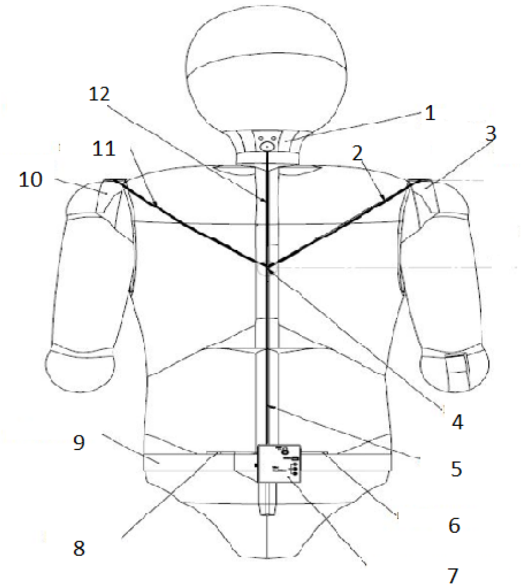
The secondary purpose of this device is to allow the user to gradually make postural corrections, which take into account the needs and anatomical specificities of the user. For example, in the case of a user who presents certain deviations of the spine, such as kyphosis, lordosis, with this device the user can gradually make corrections that over time lead to a satisfactory final result, taking into account the specifics of the user's pathology.

The device has the following advantages:

- allows real-time monitoring of postural changes occurring at the level of the user's spine and shoulders;
- it can be used to maintain the most correct position of the spine and shoulders, during the bending and lifting movements of the trunk, necessary during physical training/physiotherapy training or those imposed within various activities, as well as during ordinary household activities;
- it is adaptable according to the biometric dimensions (height and distance between the shoulders) of the user and according to the pathological specificities of his spine;
- it can be used to make gradual postural corrections in the case of a user who has certain deviations of the spine, such as kyphosis, lordosis or scoliosis, allowing the user to make small corrections over time, that ultimately lead to a satisfactory result taking into account the specifics of the user's pathology;
- the device can create warnings regarding the change in the user's posture, which can be both of a sound nature and of the type of weak electrical impulses, such as duration and intensity, applied in strongly muscled areas (such as the area of the buttocks or shoulders);
- the device allows adjusting the level of sensitivity, depending on the needs/preferences of the user;
- the device allows alerting the user not only about the change in the posture of the lumbar-thoracic area of the spine, but also of the cervical area and of the shoulders;
- the device allows the user to be alerted not only to changes in the sagittal plane of the spine's posture, but also to changes in its frontal plane;
-the device can be used daily, regardless of the environment in which the user carries out his activity, as it has small dimensions and weight and also does not restrict the natural movements of the user's body, as long as they are performed correctly from a biomechanical point of view.

The device complies with the constructive principles and calculation elements presented in scientific paper [15].

The device (see Fig.7) will be composed of a central electronic unit 7, fixed on an adjustable abdominal belt 9 and having two electrodes 6;8 connected to the outside, a flexible and inextensible wire 5, which starts at the belt level and bifurcates at the thoraco-lumbar level on the left side and respectively right, resulting in a left shoulder thread 11 and a right shoulder thread 2 respectively. The ends opposite the bifurcation point are fixed on a barrette type support 10 on the left shoulder and respectively on a barrette type support 3 on the right shoulder. The thoraco-lumbar thread is continued at the upper part 12, from the point of bifurcation, with a cervical-thoracic thread, the terminal end of which is fixed on a cervical bar type support and a fixation support 1. The three brace supports (right shoulder brace support, left shoulder brace support and cervical brace support) are made from a constructive point of view, identical. In Fig. 7 shows the principle diagram of the wearable device.



1 fixation support	7 central electronic unit
2 right shoulder thread	8 electrode
3 barrette type support	9 adjustable abdominal belt
4 connector cover	10 barrette type support
5 flexible and inextensible wire	11 left shoulder thread
6 electrode	12 thoraco-lumbar thread

Figure 7: The wearable device for postural correction

The working principle of the postural correction device is as follows:

- each of the four inextensible wires has one end fixed by means of adhesive strips of the barreta supports on the right shoulder, on the left shoulder, on the right of the spinous process of one of the C2 or C3 cervical vertebrae of the spine and respectively on the driving rod of the measuring block (digital potentiometer) and is pre-tensioned in the calibration stage;

- any change occurring during the daily activities of the curves of the user's spine, or the positions of the shoulders, will produce a change in the value of the electric voltage, at the output terminals of the linear potentiometer. The rod of the potentiometer moves as a result of the traction exerted on the thoraco-lumbar wire by one of the other three pre-tensioned wires and produces a change in the value of the electrical voltage. When the electronic system of the central electronic unit notices this change in the electrical voltage (at the output terminals of the potentiometer), in relation to the existing one during the calibration phase of the device, it checks if the value of the voltage difference is lower than the level of device sensitivity, set by the user. If its value is higher than the maximum value allowed according to the sensitivity level of the device, set in advance by the user, then the electronic system of the central electronic unit will emit a continuous sound warning signal and it will also emit a series of discontinuous electrical impulses, of low intensity and duration, perceptible on the user's skin. These warning signals have the role of causing the user to correct his posture, forcing him to return to the posture of the device's calibration phase. The signals stop when the user corrects his posture well enough so that the value of the electrical voltage, from the output terminals of the potentiometer, is in accordance with the sensitivity level of the device, previously set by the user. As long as the voltage value complies with the set sensitivity level of the device, the user can continue his activity unhindered.

The block diagram of the mechatronic postural correction system is shown in fig. 8.

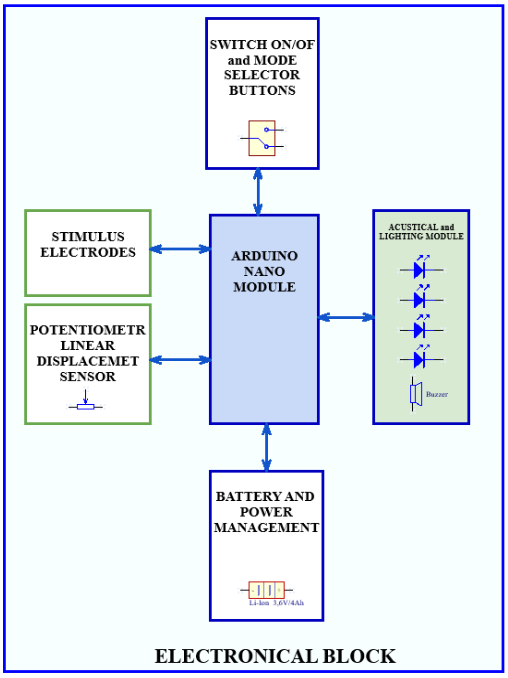


Figure 8: The block diagram of the mechatronic postural correction system

The device, due to its size and light weight, can be used daily, not restricting the natural movements of the user's body, as long as they are performed correctly from a medical point of view, but warning the user whenever the wearer's posture is not compliant with the one made in the calibration stage.

Both the maintaining and correcting posture, carried out with the help of the device, consist of self-corrections of the user's posture, as a reaction to the warning signals emitted by the correction device. The final postural correction is obtained through the accumulation of several successive mini-corrections, as a result of the psycho-physical adaptations of the user's body, to the positions imposed in each stage of device calibration, corresponding to a work session. Achieving the objective from a previous stage allows the imposition of maintaining a new posture, closer to the physiological one than the posture from the previous stage.

The device allows the user to opt for postural maintenance/correction only from the point of view of the spine, or only from the point of view of the position of the shoulders. To achieve the first variant of postural maintenance/correction, the user/third person must only adjust the tension of the cervical-thoracic thread, ignoring the tension adjustment of the left shoulder and right shoulder threads respectively. In the case of the second variant of postural maintenance/correction, the user/third person must only adjust the tension of the left and right shoulder threads, ignoring the tension adjustment of the cervical-thoracic thread.

4. Conclusions

By integrating the individual functions of the two mechatronic systems, the specialist will be able to carry out an analysis of the biomechanics of the movement, which will constitute the referential according to which he will evaluate the progress of the human subject and will also be able to provide the latter with a system that will allows him to correct his posture, develop his biomotricity and improve his neuromuscular control, all this taking place under the close supervision of the specialist.

From the point of view of the human subject, he will be able to achieve the two desired goals mentioned previously, without being obliged to go to the office/gym where the specialist works. He will be able to take advantage of the benefits of the interaction with the specialist from any location where the recovery/training session takes place. Also, the human subject will be able to set, regardless of the schedule of the specialist, the time schedule in which he will use the systems in question.

The concept of the integrative mechatronic system is that of web-based training (WBT), which is actually the generic name for any form of recovery/training/training carried out in the online environment.

The main benefits of WBT both from the point of view of the patient/athlete and from the point of view of the specialist, are related to the flexibility of the training program that each patient/athlete carries out according to the specifications of the specialist and their own availability, as well as cost efficiency, resulting from the elimination of dead times due to travel to/from the medical office or the training room.

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