TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 67, Issue Special III, Jully, 2024

DEVELOPMENT OF A CERVICAL FLEXIBILITY MONITORING DEVICE

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Abstract: *A good posture of the human body requires a musculoskeletal system without dysfunctions that allows a continuous movement, synergistic and reproducible to ensure the mobility of the limbs and the entire human body and that the entire property category is at the normal level. Any deviation from normal functioning can indicate a motor dysfunction, pathology or even changes in the functioning of the entire human body. In the modern age, the excessive use of electronic devices created in a very high dynamic is, besides their beneficial role for daily activities, also sources of mobility stress. These in turn can be installed for various reasons, unique or combined and can affect the general physical and/or mental health, allow the installation of pathologies or can change occupational comfort. In the first part of the paper, a series of aspects related to the anato-morphological characteristics of the cervical cap-gat-column system and the mobility function of the cervical joint are reviewed. In the second part of the paper, the authors analyze the methods and means of investigating the mobility of the cervical ensemble to identify non-invasive and compatible systems. In the third part of the work is described the design of a system of analysis and examination of cervical spine movements and in the fourth part are presented the results of the measurements made with the system developed by this research compared to the results obtained from the other two systems in order to evaluate the angular rotation limits of the joint cervical, of the movement in which the movement is made. In the final part of the paper are presented a series of conclusions and identify ways of future development.*

Key words: *cervical flexibility, sensorial collar, monitoring angles, ergonomic*

1. INTRODUCTION

The cervical region, also called the neck, is a well-designed structure made up of bones, nerves, muscles, ligaments, and tendons. The cervical spine is delicate, hosting the spinal cord that sends messages from the brain to control all the modules of the human body. In addition, remarkably strong and flexible, it allows the neck to move in all directions [1].

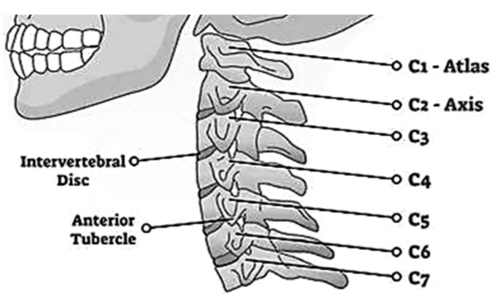


Fig. 1. Cervical region of the spine [2].

The cervical spine has seven vertebrae that can be divided into two distinct groups, both anatomically and functionally: the upper pair (C1 and C2) and the lower five (C3–C7). In addition to the 7 vertebrae (Figure 1), the cervical area also includes the following regions: joints, nerves, conjunctive tissue, muscles and spinal segments.

The rotations of the cervical area (Figure 2) are carried out in two directions: to the right and to the left. They are limited by a number of anatomical structures of the cervical spine, such as the intervertebral joints and ligaments. The maximum limit of the rotations of the cervical spine is given by the anterior longitudinal ligament, which prevents excessive extension of the spine. During rotation, relative movement occurs between the cervical vertebrae, while the cervical ligaments prevent excessive movement or lushness. [3]

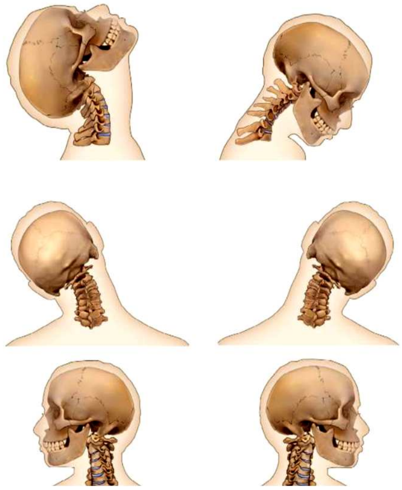


Fig. 2. Rotations of the cervical area [5].

Upper cervical vertebrae, (C1) and (C2) are different from other cervical vertebrae in that they do not have a distinct vertebral body and form a complex structure that allows for a wide range of movements [4].

Among the boundaries of the cervical area are:

- Limited flexibility in lateral rotation: lateral movements of the head are limited in the cervical area. This is due to the joints and ligaments that connect the cervical vertebrae and limit the amplitude of the lateral movement.
- Extreme extension and flexion limit: the cervical area allows flexion movement (forward tilt) and extension (reverse tilt), but there are limits in the amplitude of these movements. The bone structures and joints of the cervical vertebrae determines these limits.

As mentioned in the information on the movement of the cervical spine [5], it typically includes the following components:

1. Flexion (forward tilt): In a normal neck flexion, the chin approaches the chest. The normal range of flexion can range from 40° to 90°, with some individuals having greater flexibility.

2. Extension (reverse tilt): In a normal extension of the neck, the head tilts back. Normal extension range can range from 40° to 90°.

3. Lateral tilt (left and right movement): Lateral tilt involves moving the head towards the left or right shoulder. Normal side tilt range can vary from 22°- 50° in each direction.

4. Rotation (turn motion): Rotation allows the head to move to the left and right. The normal range of rotation can vary from 45°-90° in each direction.

It is important to mention that the exact values of these rotation angles may vary for each person depending on the anatomical and anthropometric configuration and specific medical evaluation. In addition, certain medical conditions, injuries or conditions can affect flexibility and normal range of motion in the cervical area. Based on these assessments, a normal range of movement specific to each individual can be established.

Cervical spine biomechanics is complex and involves a delicate balance between stability and mobility. Disorders that disrupt this balance can result in different forms of pain, limited range of motion, and many other symptoms [6].

The cervical spine is a complex structure that plays an essential role in supporting the head and allows the neck to move along with it. However, it is vulnerable to a number of pathologies that can cause pain, discomfort and even disability. Disorders manifested in the functioning of the cervical spine can be caused by a variety of factors, including aging, degeneration, trauma, incorrect posture and injuries through repetitive effort. Symptoms of cervical spine problems may vary depending on the specific disorder, but there are also common symptoms such as neck pain, stiffness, headache, and numbness or tingling in the arms or hands, weakness, difficulty during the walking cycle or decreased manoeuvrability.

Usually, the assessment of cervical spine problems, carried out by specialized medical professionals, involves a detailed physical examination, a thorough analysis of your medical history and a series of diagnostic imaging and examination tests. Treatment options for cervical spine problems, established by specialist doctors, will depend on the type of underlying disorder to which alternative therapies may be added.

In addition, preventive measures that can help reduce the risk of developing cervical spine dysfunction include maintaining a good posture, practicing safe lifting/sitting techniques, maintaining a balanced physical activity, avoiding sitting or standing for extended periods and using appropriate ergonomic arrangements when working at the office, at the computer or at a workbench. Regular exercise and stretching of the limbs can also help to improve the mobility and flexibility of the spine, this can help prevent the installation of mobility dysfunctions or the positioning of the entire human body in relation to different activity spaces.

2. METHODS AND MEANS FOR MONITORING AND RECORDING THE MOVEMENTS OF THE CERVICAL COLUMN

The techniques for monitoring, tracking and recording the movements of the cervical spine involve a series of methods and means based on the characteristics of the musculoskeletal system, consisting of the head, neck, cervical spine. Because this process is dynamic, the evolution of these characteristics is measured in real time and the hardware systems transform them into a flow of successive angular values of the positions of this assembly in relation to the entire human body or the activity environment.

As mentioned in many research, the mobility of the cervical spine is difficult to investigate properly because of its anatomical structure and compensatory movements. Thus, in current practice, different methods have been devised to obtain a reliable measurement of the range of cervical motion (range of motion - ROM) without using invasive or cumbersome elements.

The choice of method depends largely on the intended medical/ergonomic objective, whether it is just a clinical screening activity or a detailed investigation of the function of the musculoskeletal system of the head-neck assembly, especially in post-traumatic diseases of the cervical spine.

In the case of clinical screening, goniometers and inclinometers (mechanical have electronics) are reliable instruments and with the possibility of reproducible measurements for the evaluation of the maximum amplitude of cervical movements, including flexion-extension, and rotation and lateral flexion. On the other hand, the construction of portable sensory systems, easy to use and record the sizes necessary to evaluate the movement limits of the head-neck assembly and to provide complete information in real time, appears as a useful variant, effective and fast for the research stages or even in the initial screening evaluation procedures.

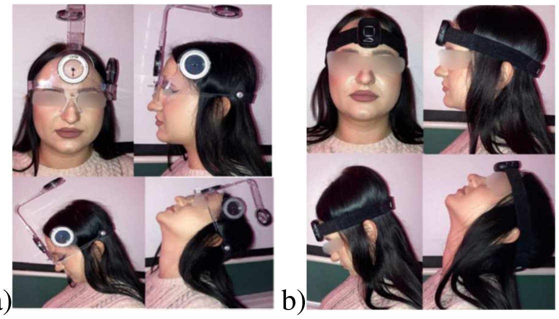
In return, in the case of diagnostic examinations and monitoring of cervical conditions, preference is given to the use of x-rays and 3D kinematic analysis with optoelectronic scanners. These techniques provide a more detailed investigation, providing precise information about the biomechanics and kinetics of the head-neck assembly, which leads to a more complete and accurate assessment of cervical function. [7].

2.1 The tools used in research development

Goniometers, mechanical and electronic inclinometers (Figure 3) are useful devices and easy to handle, but the recorded values are only evaluation sizes, but, without too high measuring accuracy and can be influenced by several environmental factors.

Even if the mechanical goniometer system is more complex (Figure 4.a), however, electronic systems for measuring the angle of inclination of the system containing the cervical spine are more useful and are based on real-time recording of the range of motion (ROM) using wireless sensors placed on the forehead of the subject (Figure 4.b).

Fig. 3. Mechanical and electronic goniometers and inclinometers.



a) b)

Fig. 4. Mechanical inclinometer with three clocks (a) and wireless electronic system Meditouch 3D tutor (b).

Fig. 5. Sistemul de senzori Xsens MVN isi modul wireless.

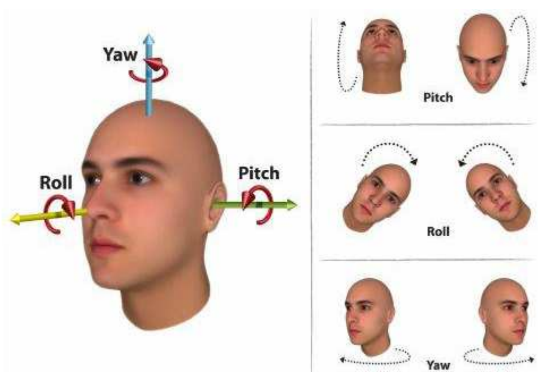


Fig. 6. Triortogonal axis system and angles for rotation movement [5].

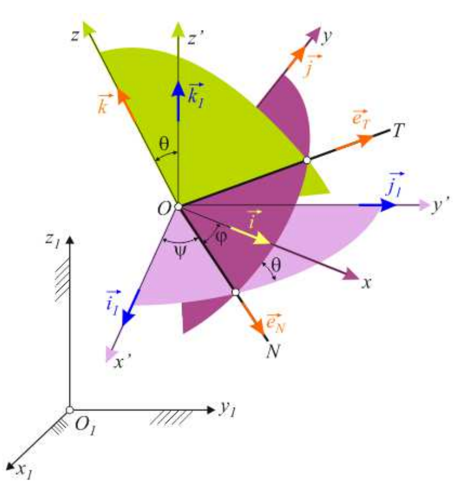


Fig.7. Definition of Euler's angles [8].

Another important system used to evaluate cervical movements is the Xsens MVN sensor assembly, which is developed as a motion capture system and uses measuring units inertial (IMU) to track body movement. When it comes to the cervical region, Xsens MVN was used to track the movement of the head and neck along the three directions of the tri-orthogonal system.

Two inertial Xsens 00B46A54 and 00B46D0C sensors were used to measure neck flexion movements. The Xsens 00B46A54 sensor was mounted on the head, while the Xsens 00B46D0C sensor was located on the cervical region.

2.2. Theoretical foundation of the movements of the head-neck and cervical spine system

The movements of this system in its entirety (Figure 6) are defined by a series of parameters through which one can evaluate the state of normality or discomfort in which the musculoskeletal system may be located.

To describe the orientation of a system in three-dimensional space, Euler's angle theory is used.

This theory is based on three angles: pitch angle, roll angle and yaw angle. These angles represent and characterize the movements around the corresponding axes (Figure 6).

Each of the angles mentioned are defined as follows (Figure 7):

- The pitch angle represents the tilt motion of the system around its horizontal axis, perpendicular to the direction of forwardness. This angle, theoretically, can vary between -90° and +90°;
- The roll angle represents the tilt motion of the system around its longitudinal axis. The inclination axis is parallel to the direction of the system forward, and this angle, theoretically, can vary between -180° and +180°;
- The angle of yaw – represents the rotation movement around the vertical axis, and this angle, theoretically, can take values between -180° and +180°.

Considering the head-neck-cervical columandly as a solid type system with an Oxyz landmark that moves in a fixed $O_1x_1y_1z_1$ and also that in the origin of O there is another mobile landmark, solidarly linked to the rigid, which has the axes always parallel to the axes of the fixed landmark, $Ox'y'z'$, then if the position of the Oxyz mobile landmark is known, the position of the solid will also be known. As shown in [8] during solid motion, both the position vector of the movable origin and the angles of Euler (Figure 7) will be time functions:

$$\vec{r}_0 = \vec{r}_0(t), \psi = \psi(t), \varphi = \varphi(t), \theta = \theta(t) \qquad (1)$$

Accordingly, the passage of the landmark from the position given by the parameters ψ, φ, θ in an infinitely neighboring position defined by $\psi+d\psi, \varphi+d\phi, \theta+d\theta,$ in an elementary time *dt*, it will be obtained by elementary rotations around the axes *Oz', Oz* and *ON,* with angular speeds: $\dot{\psi} = d\psi / dt$ around the axis *Oz',* $\dot{\varphi} = d\varphi / dt$ around the axis *Oz* și $\dot{\theta} = d\theta / dt$ around the line of knots *ON*. If it is noted with $\vec{\dot{\psi}}, \vec{\dot{\varphi}}, \vec{\dot{\theta}}$ angular velocity vectors oriented by axes *Oz', Oz* și *ON* and having the respective modules equal to $\dot{\psi}, \dot{\varphi}, \dot{\theta}$, it can be said that the vector $\vec{\omega}$ is equal to:

$$\vec{\omega} = \vec{\dot{\psi}} + \vec{\dot{\varphi}} + \vec{\dot{\theta}} \qquad (2)$$

So, his components $\vec{\omega}$, are going to be:

$$\vec{\dot{\psi}} = \dot{\psi} \begin{bmatrix} \sin\theta \cdot \sin\varphi \\ \sin\theta \cdot \cos\varphi \\ \cos\theta \end{bmatrix}, \quad \vec{\dot{\varphi}} = \dot{\varphi} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}, \quad \vec{\dot{\theta}} = \dot{\theta} \begin{bmatrix} \cos\varphi \\ -\sin\varphi \\ 0 \end{bmatrix} \qquad (3)$$

where does the module of it result as:

$$\omega^2 = \dot{\psi}^2 + \dot{\varphi}^2 + \dot{\theta}^2 + 2\dot{\psi}\dot{\varphi}\cos\theta \qquad (4)$$

With these relations and considering the case of a rigid fixed-point solid assimilated to the head-neck-cervical column assembly, the determination of the laws of motion as well as the reactions that develop in the connection located in the fixed point considers that the main joint is a spherical one, thus yielding two sets (5) and (6) of Euler's scalar equations.

$$\begin{aligned} (\varepsilon_y + \omega_x\omega_z) r_G &= X + X_O, \\ (-\varepsilon_x + \omega_y\omega_z) r_G &= Y + Y_O, \\ -(\omega_x^2 + \omega_y^2) r_G &= Z + Z_O. \end{aligned} \qquad (5)$$

și

$$\begin{aligned} J_x\varepsilon_x + \omega_y\omega_z(J_z - J_y) &= M_x, \\ J_y\varepsilon_y + \omega_z\omega_x(J_x - J_z) &= M_y, \\ J_z\varepsilon_z + \omega_x\omega_y(J_y - J_x) &= M_z. \end{aligned} \qquad (6)$$

In conclusion, the cervical spine is a complex structure consisting of interconnected vertebrae, which allows the movement and flexibility of the head. Treating the cervical spine as a spherical joint simplifies the analysis of head movements, and using Euler angles in a three-dimensional reference system facilitates the description of these movements.

The importance of the cervical spine in evaluating the range of motion was highlighted by theoretical substantiation and served as the basis for the development of the device. This is why the sensor collar device designed and built in this research is necessary for monitoring the flexibility of the cervical spine while being versatile and fast in obtaining answers in real-time.

3. SENSORY SYSTEM FOR ASSESSING AND RECORDING THE FLEXIBILITY OF THE CERVICAL COLUMN

The analysis system of the flexibility of rotation movements of the cervical head-neck-column assembly for the identification of normality/anormality states includes the following functional modules: flexion sensor system, Arduino type acquisition plate, etc, display system, accessories.

For the realization of this device, components that are the basis of its operation were selected, considering the objectives related to construction and performance to ensure a small size and weight, without compromising the reliability of the system.

Initially, the device designed to monitor cervical flexibility was prepared to be calibrated, tested and then used on a set of subjects as different from an anthropometric point of view.

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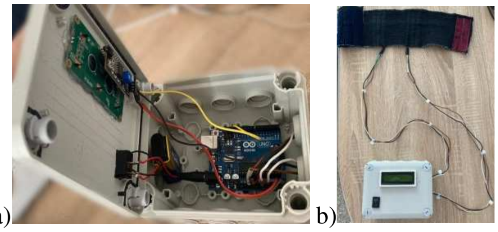

Fig. 8. The sensorial collar system.

Fig. 9. The sensorial collar and the display system.

Once the device is turned on, the sensors measure the range of motion of the cervical area and as the neck performs variable movements the LCD system displays in real time the flexion angles of the sensors, providing information about this range of motion (Figure 9). The data recorded with the developed sensory system is compared with the other two professional Xsens MVN and 3D Tutor systems. For example, during the execution of movements, the Xsens MT Manager software provided information about the rotation angles and the deviation from the neutral position of the head in each direction. This information shall provide relevant data for the assessment of movements and for the study carried out.

4. RESULTS

The experimental procedure was conducted in a systematic and controlled manner, thus ensuring the achievement of accurate and consistent data. The graphs obtained from the processing of data in Xsens highlight the variations of angles in the three axes (x, y, z) depending on the type of motion executed (Figure 10).

The comparison was also executed with the 3D Tutor system [9] which indicates the range of motion (ROM) in the analyzed cases (Figure 11). The three participants have different anthropometric characteristics, a fact evidenced by the angular values recorded (Table 1).

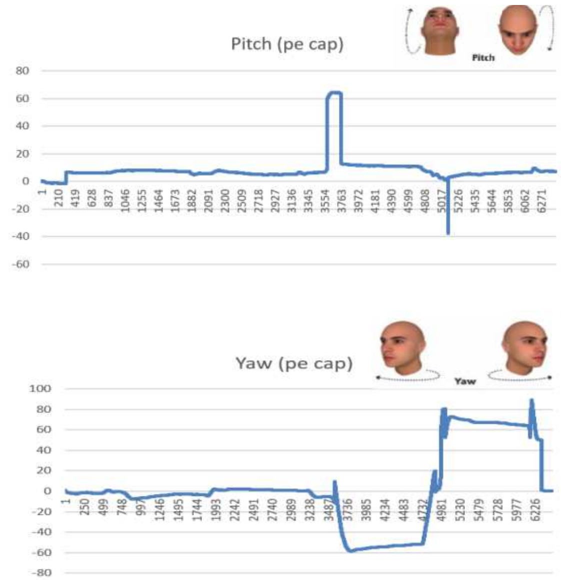

Fig. 10. Example of results recorded with Xsens MVN.

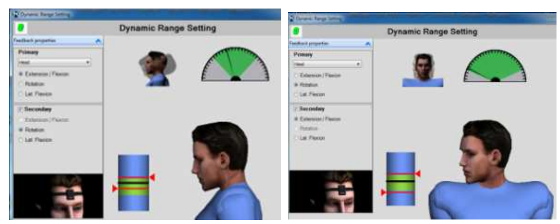

Fig. 11. Exemple de rezultate înregistrate cu 3D Tutor.

Table 1

Angular values measured on 3 subjects

Subject	Flexion (°)	Extension (°)	Left lateral flexion (°)	Right lateral flexion (°)
Subject 1	84	67	35	40
Subject 2	70	60	33	30
Subject 3	45	37	20	18

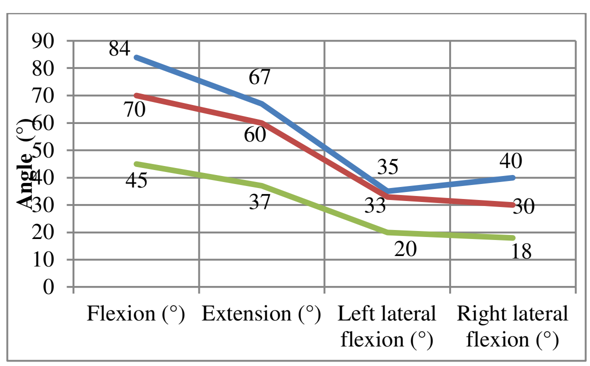

Fig. 12. Results recorded with the sensorial collar.

The measurements were made for the following types of movements: flexion, extension, left and right lateral flexion. The order of these movements has been kept constant for all subjects.

The values obtained for flexion, extension and lateral flexion provided information about the amplitude of the cervical movements of the subjects. These data were interpreted in the context of assessing cervical flexibility, identifying differences between movements and subjects, and monitoring progress over time in the event of specific treatment or intervention.

The graphs obtained highlight the variations between the movements performed by the subjects. It was noted that subject 1 with a sports constitution recorded an extensive range of motion in flexion (84°) and extension (67°), as well, while subject 2 and subject 3 showed lower values in these movements.

As for the lateral flexions, it was found that subject 1 and subject 2 recorded relatively similar values, while subject 3 recorded lower values, suggesting a restriction in this type of movement.

Analyzing the chart, variations were observed between the measured movements. These differences can be attributed to individual differences in cervical flexibility and serve as a basis for assessing progress over time and treatment effectiveness in subject 3.

5. CONCLUSIONS

As shown in other research regarding the determination of the flexibility of the cervical cap-gath-column assembly and the effects on the behavior of the human subject in the performance of certain activities is a very important field in regarding the achievement of the state of occupational comfort. The system proposed by this paper presents a series of specific features - versatile system, easy to handle, safe, reproducible measurements that are complemented by a simple and fast monitoring procedure [10-11].

The values obtained from the application of this developed system are checked with the results obtained from more complex records with Xsens MVN and 3D Tutor systems, to obtain a more efficient system, easy to build according to needs and with important results.

The system also allows the periodic application of calibration and validation modalities to monitor and signal the level of changes in the movement forms of the cervical cap-gath-column assembly. Following the first experiments carried out according to the methodology proposed by this research, a number of important aspects could be found that may manifest during the tests. Mainly environmental conditions (variance of temperature, noises, vibrations, random light radiation, etc.) can influence the concentration, attention and participation of the sample of subjects, sometimes there are errors in registration.

However, by permanently controlling and adapting the way the subjects react and the environment in which the cervical flexibility monitoring process takes place can be identified and determine a normal level/abnormal occupational comfort that can then be compared to values obtained by other methods of analysis (biomechanical analyses).

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Dezvoltarea unui dispozitiv de monitorizare a flexibilitatii cervicale

O postura buna a corpului uman necesita un system musculoscheletal fara disfunctii care sa permita o miscare continua, sinergica si reproductibila pentru a putea asigura mobilitatea membrelor si integral a corpului uman si ca toata categoria de proprietati sa se afle la nivel normal. Orice abatere de la starea de functionare normala poate indica o disfunctie motorie, o patologie sau chiar modificari ale functionarii intregului organism uman. In epoca moderna, utilizarea excesiva a dispozitivelor electronice create intr-o dinamica foarte mare constituie, pe langa rolul benefic ale acestora pentru activitatile zilnice, si surse de stress de mobilitate. Acestea la randul lor se pot instala din diferite cauze, unice sau combinate si pot afecta starea generala de sanatate fizica si/sau psihica, pot permite instalarea de patologii sau pot modifica confortul ocupational. In prima parte a lucrarii sunt trecute in revista o serie de aspecte legate de caracteristicile anato-morfologice a sistemului cap-gat-coloana cervicala si respectiv ale functiei de mobilitate a articulatiiei cervicale. In partea a doua a lucrarii autorii analizeaza metodele si mijloacele de investigare a mobilitatii ansamblului din zona cervicala pentru a identifica sistemele non-invazive si compatibile. In partea a treia a lucrarii este descrisa conceperea unui sistem de analiza si examinare a miscarilor coloanei cervicale, iar in partea a patre sunt prezentate rezultatele masuratorilor realizate cu sistemul dezvoltat prin aceasta cercetare in comparatie cu rezultatele obtinute de la celelalte doua sisteme in pentru evaluarea limitelor unghiulare de rotatie a articulatiei cervicale, a mdului in care se realizeaza miscarea. In partea finala a lucrarii sunt prezentate o serie de concluzii si sunt identificate modalitatile de dezvoltare viitoare.

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