A WIRELESS ACQUISITION SYSTEM FOR MONITORING THE INFLUENCE OF LOADS ON VERTEBRAL COLUMN BEHAVIOUR

João Eduardo Castro Ribeiro, João Paulo Pereira do Carmo

Polytechnic Institute of Bragança, Bragança, Portugal

jribeiro@ipb.pt

Abstract: This paper presents a wireless acquisition module (WAM). This allows the monitoring of heavy loads influence on vertebral column's behaviour. Each module makes the electromyography (EMG), to measure the electric potentials on the iliocostalis and longissimus thoracis muscles, and use a dual-axis accelerometer to get the movements of the body, in order to obtain the complete behaviour of the vertebral column. The solution chosen to transmit the body's measured signals for further processing, is a wireless link working in the 433 MHz ISM band. The acquired information is transmitted with a maximum rate of 40 kbps, a resolution of 9.8 µV, and accommodates two analog channels. An analog channel with differential input connected to the electrodes, is used to measure the EMG signal, while the remained channel is used in the patient's movements measurements. The dimensions of the proposed acquisition system are about 7×5×2 cm, and will help to understand the influence of heavy loads as a risk factors in the vertebral column, such as the scoliosis and lordosis.

1   INTRODUCTION

The human posture has been an object of studies in biomechanics, once some deviations of structural and functional positions induce an unbalanced body. These deviations usually, affects the vertebral column and are caused by physical efforts, bad postures in work, deficiency in sustentation muscles, infections and congenital causes. The main pathologies of vertebral column caused by the referred deviations, are the scoliosis and lordosis. Sometimes these pathologies appears in children when they carry the heavy backpacks on the backs, in this case, it's very important monitoring the influence of loads (backpack weight) in vertebral column behaviour.

The vertebral column has very important functional requirements, which the most significant are: it carries and supports the thoracic cage, maintaining the balance between it and abdominal cavity; it gives attachment to many muscles of the pectoral and pelvic girdles; it provides anchorage for many powerful muscles, which move the vertebral column, these same muscles maintaining the balance and erectness of the human trunk; it acts as shock absorber, by virtue of its curvatures and the intervertebral discs, receiving and distributing the impacts associated with the dynamic functioning of the body; it is able, by virtue of its flexibility, to produce and accumulated moments of force as well as to concentrate and transmit forces receiving from other parts of the body (Palastanga *et al*, 2002).

When someone carries a heavy object like a backpack on the back, the center of gravity of body changes and it will be necessary some adaptations to maintain the balance, these adaptations are possible because the action of powerful muscles like iliocostalis or longissimus thoracis, and the relative movement among the intervertebral discs. In the children who carries heavy backpacks repeatedly and for long time they could suffer injuries in the vertebral column that can develop pathologies like scoliosis. Figure 1 show vertebral column with a scoliosis.

The study of influence of backpack weighs on the vertebral column of children is an important issue, that has been worked by many researchers for years (Nissinen *at al*, 1994; Widhe, 2001; Skaggs *et al*, 2006). In this work we try a different approach, applying indirect information, using the electrical potential generated by the muscles, when they contract and when they are rest. The technique which could measure this electrical potential is the

electromyography (EMG). Based on the results of EMG, combined with the movements of the body, measured by the accelerometers, it is possible to know by numerical simulation, the displacement occurred on the insertions points between the muscles and the vertebral column (Conceição, F. *et al*, 2007; Pato, M. *et al*, 2007). Using these values of displacements in a finite element code, like ANSYS®, we can compute the value of stress field in the vertebral column, especially it is possible to observe where are the points more affected and the respective stress value.

Figure 1. Radiograph showing a vertebral column with a scoliosis.

2 KINEMATICS

The skeletal system of the trunk comprises the pelvis, vertebral column and rib cage. The vertebral column is divided into four regions: cervical; thoracic; lumbar and sacrum.
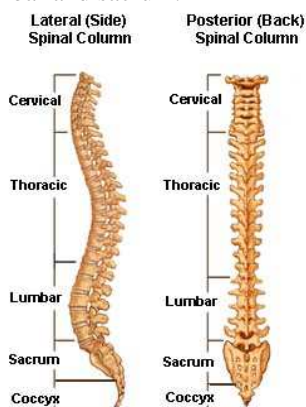

Figure 2. The regions of the vertebral column (Bridwell, 2007).

The vertebral column is a flexible rod with seven mobile segments in the cervical region, twelve segments in the thoracic region and five segments in the lumbar region. The fourth region of the vertebral column, the sacral-coccyx region, includes nine fused vertebrae that together with the right and left ilia form the pelvis.

Two adjacent vertebrae and their interposed intervertebral disk form a motion segment of the vertebral column. Each segment has six degrees of freedom (DOF). In the vertebral column, there are two types of joints: the intervertebral joints between the vertebrae and adjacent disks and the facet joints between the facets (articular processes) of the neighbouring vertebrae. Movement at the intervertebral and facet joints of the same motion segment is coupled.

The intervertebral disks are flexible spacers between adjacent vertebrae. The disk consists of a central nucleus pulposus, which is a ball of hydrophilic jelly, and the outer annulus fibrosus, a series of laminae formed by collagen fibers. The disc height (thickness) increases from the cervical lumbar region from about 3 mm to 9 mm.

Any change in vertebral column posture involves the joined movement of several motion segments. People cannot move the individual motion segments independently.

Kinematics of the vertebral column deals either with the specific motion segments or with the entire region of the vertebral column or both (Zatsiorsky, 1998).

Each of the motion segments has six DOF: because the intervertebral disks can deform, the vertebrae, in addition to being able to rotate, and translate. The vertebral column as whole can produce only three movements: flexion-extension, lateral flexion and axial rotation. The vertebral column movement results from concurrent rotation and translation of the vertebrae. The amount of motion available at various motion segments depends mainly on the size of the disks, while the orientation of the facet joint surfaces, which changes from region to region, defines the direction of the allowable movement.

The relative movement of the motion segments of the vertebral column is allowed by an elastic connection provide by the intervertebral disks. Vertebral flexion and extension causes compression in one part of the disk and traction in another part. When a relative motion between two consecutive vertebrae is analyzed, the lower vertebra is usually considered a fixed body and the upper vertebra is treated as moving body. The coordinate axes are

taken along the inferior and posterior margins of the stationary, lower vertebra.

Because the disks can deform, the same resultant force and torque being applied to various vertebrae produces different movements depending on the disk stiffness and its dimensions, height and diameter.

The rotation and translation of the vertebrae results in a torsion and bending of intervertebral disks. In case of torsion, the disk is subjected to equal and opposite twisting couples at the two adjacent vertebrae. The axial rotation, α_a, is the angle by which the top vertebra turns with respect to the bottom vertebra. For a disk of a height H, radius r, and cross-sectional area A, on which a torque M_a is acting, the angle of twist is:

$$\alpha_a = \frac{M_a H}{G I_p} \qquad (1)$$

where G is the shear modulus and I_p is the polar moment of inertia. The bending occurs when the line of force does not coincide with the symmetry axis of de column, and appears a bending stress (Adams and Dolan, 1991). The equation relating angular displacement of the disk, α_b, with the applied bending moment, M_b, is

$$\alpha_b = \frac{M_b H}{E I_d} \qquad (2)$$

where E is the modulus of elasticity and I_d is a diametral moment of inertia, $I_d = 0.5 I_p$.

Considering that the column is loaded with two forces, F and –F, acting in opposite directions along the same line of action.
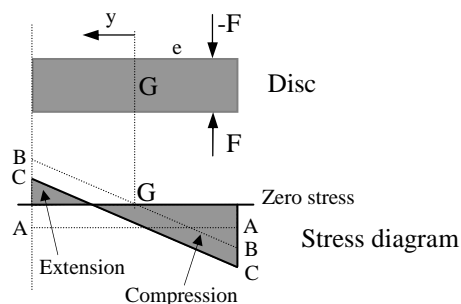

Figure 3. A model of intervertebral disk bending: the stress distribution is in vertical cross section of a column loaded by off-center forces, F and –F.

The line of action does not pass through the center of gravity (G). The center of gravity is the location of the resultant force acting in compression and proportional to the elements of area. The column is under joint action of compression and bending and is stressed correspondingly (Adams and Dolan, 1988).

The compressive stress is F/A, where A is the area of the horizontal section. The bending stress is M.y/I, where M is the bending moment; y is the distance from the neutral line of the column (this is the line that experiences neither compression nor tension during bending); and I is the area moment of inertia. The bending moment equals the product F×e, where e is the eccentricity (distance from the line of force to the center of the column). This distance is crucial in provoking bending stress.

The relative movement of a vertebra with regard to the vertebra immediately below it can be viewed as a combination of rotation and translation. An infinite number of combinations of rotation and translation can describe the same movement. To simplify the kinematics analysis is assuming that a vertebra rotates around a pole whish (1) is located on the inferior end plate of the moving vertebra and (2) moves parallel to the inferior margin of the reference vertebra, axis X of the coordinate system.
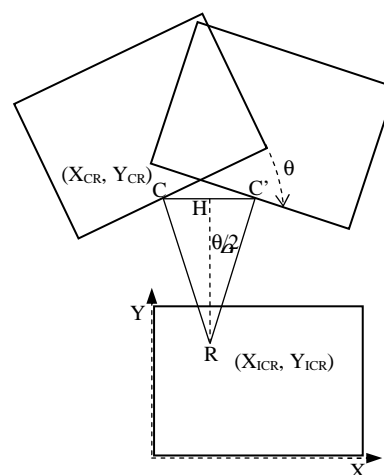

Figure 4. An illustration of a vertebra that has rotate and translated from an initial position to a final position about an ICR located at *R*. The center of rotation C translates to C'. H is the midpoint of interval CC'. θ is the angle of rotation.

In framework of this model, the vertebral motion is viewed as a translation along the axis X and the rotation around the pole, the center of rotation (Cossette, J. *et al*, 1971). Because a rotation about the instantaneous center of rotation (ICR) is equal to the rotation about any parallel axis, the angle subtended at the ICR by the arc of motion of C is equal to the angle of rotation (θ) undergone by the whole vertebra. Because the triangle CC'R is an isosceles triangle, HR = CC'/2tan(θ/2), where HR and CC' are the height and base of the triangle. If

the location of the ICR is experimentally determined, location of C can be found as

$$X_{CR} = X_{IRC} - \frac{CC'}{2} \qquad (3)$$

$$Y_{CR} = Y_{IRC} - \frac{CC'}{2\tan\left(\theta/2\right)} \qquad (4)$$

The position of the ICR is determined by the location of the center of the rotation, the translation of the vertebra in parallel with the axis X and the rotation of the vertebra. In some patients, as compared with healthy people, the ICR is displaced. The displacement can be explained in terms of the three mentioned factors. For example, elevation of the ICR can occur only when the translation is decreased, the rotation is increased, or both. The three mentioned mechanisms can be explained by a combination of biomechanical changes, such as increased muscle pull.

3 WIRELESS ACQUISITION MODULE

The application described on this paper, needs wireless acquisition modules (WAMs), to simultaneously acquire the information from the muscles and the movements of the patient. In the first case, the use of standard electrodes makes possible to measure the electrical potential, above the patient's tissue. In the second case, a dual-axis accelerometer will measure the motion and the positioning of the patient.

Normally, the barrier layer forms the typical 50 kΩ impedance for 1 cm^2 of skin. There is also a skin potential between the inside and outside of the barrier layer of typically 30 mV. When the skin stretches, the skin potential decreases to about 25 mV and this 5 mV change is what we observe as motion artifact (Webster et al, 1984). These are the signals that are being acquired by the electrodes, and further amplified by the instrumentation and further converted to the digital domain.

The Figure 5 shows the architecture of a WAM, which is composed by an amplifier, followed by an analog-to-digital converter (ADC) to convert the amplified EMG signals to the digital domain, and a dual-axis accelerometer.

The amplifier is a chain composed by the MAX4460 instrumentation amplifier, and by the MAX4249 single-ended low-noise amplifier. The MAX4460 was chosed due to its characteristics, e.g., the low-power consumption, the ultra low-power input

current and the increased common-mode rejection performance. This chip amplify the differential signals obtained from the two potentials collected with the EMG electrodes, placed in the patient's skin. The high input impedance of this amplifier matches with the small-signal differential voltages collected in the electrodes. The microcontroller automatically selects the most appropriated gain of this amplifier, which can be: one, ten and one hundred. The acquired signal after being amplified by the MAX4460 and converted to a single-ended signal, is further amplified by the MAX4249. It was selected this amplifier, due to its low-noise characteristics, in order to not contaminate the EMG signal.
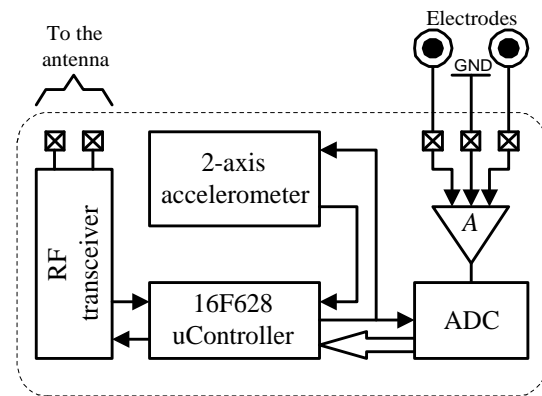

Figure 5: The block diagram of the wireless acquisition module.

The analysis of the EMG signal is made in the amplitude domain, thus, before proceeding to the ADC conversion, it is required a peak detection of the amplified EMG signal, followed by an integration (Robertson et al, 2004). This is mandatory process eliminates the fluctuations that characterise the EMG signal. As shown in Figure 6, the discharge of the capacitor, is made with a bipolar junction transistor (BJT). The pulse transformer is made on the WAM's PCB, in order to not compromise the compactness of the WAM. The circuit size WAM achieved, using surface mount (SMDs) devices, for all the components, including the micropower, rail-to-rail output, dual op-amp MAX4464, used on the circuit of the integrator.

The measurements of the motion and the positioning of the patient's body is made with the use of the ADIS16003, dual-axis accelerometer of MEMS type. This chip connects to the microcontroller, by way of an integrated Serial Port Interface (SPI). This accelerometer was chosed, due its build-in temperature sensor. This sensor is very useful to

make the compensation of the temperature gradients, specially when the devices are placed in contact with the human body.
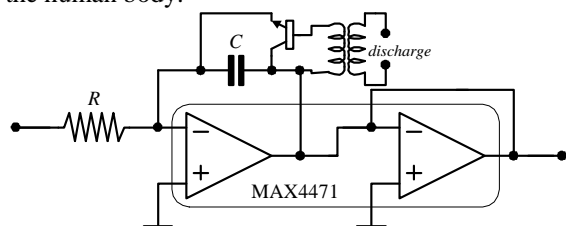

Figure 6: Integration circuit.

The microcontroller PIC16F628 from the Microchip manufacturer, controls all the electronics, as well as the communication between WAMs, and from the WAM and the external base-station, where all the processing of the acquired data is made by a health professional, or a medical doctor. It was selected the BiM433 radio-frequency (RF) transceiver, from the Radiometrix manufacturer to wirelessly send the data. A set of routines and services were developed to make the RF communication the most reliable as possible. The most important of these routines are the Manchester line coding, used to solve de DC balancing problem in the communication, when long sequences of zeros or ones must be transmitted. It was included a mechanism of error control on all data frames (information, control and acknowledge frames), e.g., the CRC field. This field makes the detection of transmission errors on the received bitstream (Schmidt, 2000). To make the multi-element communication possible and reliable, the WAMs use the Carrier Sense Multiple Access with Collision Avoidance protocol (CSMA-CA) to start the transmissions. This simplifies the management procedures of the communication among modules, and between the base-station. This makes easy to place (or remove) new WAMs on the clothes of patients, in a plug-and-play fashion.

4 CONCLUSIONS

It was described on this paper, a wireless acquisition module, which will be used on the diagnosis of vertebral column risk factors, such as the scoliosis and lordosis. These factors normally associated to appears in children when they carry the heavy backpacks on the backs. Thus, it's of extremely importance to characterise the influence of heavy loads (backpack weight) in the vertebral column behaviour. This solution fits the medical doctors requirements for an easy placement and removal of the WAMs. This is true for the target application, because it is needed only with a low number of WAMs (no more than five), making possible to mount a wireless network with these plug-and-play modules. The main advantage of this solution, is the maintenance of the mobility and lifestyle of patients during the diagnosis.

A set of two alkaline 1.5-V class AA bateries supplies the wireless acquisition module, which have an estimated power consumption of xyz mW.

REFERENCES

Adams, M., Dolan, P., 1991, A technique for quantifying bending moment acting on lumbar spine in-vivo, Journal of Biomechanics, Vol. 24, pp. 117-126.

Adams, M., Dolan, P., Hutton, W., 1988, The lumbar spine in backward bending, Spine, Vol. 13, pp. 1019-1026.

Choi, P., *et al*, 2003, An experimental coin-sized radio for extremely low-power WPAN (IEEE 802.15.4) application at 2.4 GHz, IEEE Journal of Solid State Circuits, Vol. 38, No. 12, pp. 2258-2268.

Conceição, F. *et al*, 2007, Modelação do actuador músculo-tendão: os elementos elásticos em série como slemento central de potenciação de força, Proceedings of CMNE/CILAMCE, *In Portuguese*.

Cossette, J. *et al*, 1971, The instantaneous center of rotation of the third lumbar intervertebral joint, Journal of Biomechanics, Vol. 4, pp. 149-153.

Bridwell, K., 2007, http://www.spineuniverse.com/displayarticle.php/article1286.html.

Kaggs D., *et al*, 2006, Back pain and backpacks in school children, Journal of Pediatric Orthopedy, Vol. 26, Nr. 3, pp. 358-363.

Nissinen M, *et al*, 194, Anthropometric measurements and the incidence of low back pain in a cohort of pubertal children, Spine, Vol. 19, Nr. 12, pp. 1367-1370.

Pato, M., Martins, J., Pires, E., 2007, Um modelo de elementos finitos para músculos esqueléticos, proceedings of CMNE/CILAMCE, *In Portuguese*.

Robertson, D., *et al*, 2004, Research methods in biomechanics, Human Kinetics.

Schmidt, T., 2000, Microchip Technology Inc., CRC generation and checking, Application note AN730.

Webster, J. *et al*, 1984, Reducing motion artifacts and interference in biopotential recording, IEEE Transactions on Biomedical Engineering, Vol. 31, No. 12, pp. 823-826..

Widhe T., 2001, Spine: posture, mobility and pain - A longitudinal study from childhood to adolescence, European Journal of Spine, Vol. 10, Nr. 2, pp. 118-123.

Palastanga, N., *et al*, 2002, Anatomy and human movement, Fourth Edition, Edited by Butterworth Heinemann, pp. 445-537.

Zatsiorsky, V., 1998, Kinematics of human motion, Edited
    by Human Kinetics, pp. 311-326.