Vertebral Metrics
Automation of a Non-invasive Instrument to Analyse the Spine

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Keywords: Spinal Column, Biomechanics, Non-invasive, Medical Device, Stereo Vision.

Abstract: Back pain is a major health problem in modern society. It is known that the main responsible for this symptom are the biomechanical changes in the spinal column. Thus, it is important to develop an instrument that evaluates in a global way the spinal column in a standing position. For that purpose, a complete innovative and non-invasive system – the Vertebral Metrics – has been built. The Vertebral Metrics is a semi-automatic equipment designed to identify the spatial position of each spinal process from the first cervical to the first sacral vertebra. Using a camera and a laser diode the recognition is achieved with software capable of distinguishing prominent blue marks that identifies each spinous process. After the validation process it was concluded that the Vertebral Metrics is a reliable and valid instrument. However, the time required for a completely scan is still too long for practical use. Thus, we are presently working on the automation of this medical device by developing a new prototype. The process will comprise several modifications in the equipment as the introduction of fluorescent markers, UV lights and two video cameras. The identification of the vertebras will be performed by the stereo vision method. The software must be adapted to the new assembly.

1 INTRODUCTION

Back pain has affected humans throughout out recorded history and it is well documented to be a major health problem in modern society (Alexandre, 2001, Dankaerts, 2006). It is the leading cause of activity limitation and work absence (Dionne, 2006) so it has a significant impact on individuals, families, communities, governments and business (Hoy, 2010). In fact, the incidence of rachialgia is so high that it must be studied as if it were an epidemic and social disease (Knoplich, 2003; Galukande, 2005). Most researchers suggest that about 80% of the individuals experience back pain at some point of their life and, from those, 80 to 90% of the pain is caused by mechanical changes in the spine (Najm, 2003; Quaresma, 2010).

Currently, many options are available to evaluate the spine. There are several types of diagnostic imaging technologies to assist in identifying the anatomical changes, responsible by back pain. However, very few of them are ionising radiation free and do not allow the analysis of the spinal column in a vertical standing position. Furthermore they tend to evaluate only parts of this osseous structure (Secca, 2008). The radiological studies, particularly X-rays, are the most widely used methods for assessing the spinal column curvatures in a global way, however, since it uses ionizing radiation, it is not possible to use them in general population (Harlick, 2007; Pinel-Giroux, 2006). X-rays are associated with 0.6 – 3.2% of cumulative risk of cancer to age 75 years old (Gonzales, 2004) so its use must be reduced to a minimum.

Non-invasive equipment for evaluation of the spine is commercially available, but often only perform partial scans of the spine or are extremely expensive (Hinman, 2004; Quaresma, 2013). Thus, the development of non-invasive methods to evaluate the spine in a standing position in a global way is needed to attain a better insight into back disorders (Quaresma, 2009).

For that purpose, the Vertebral Metrics was built. It is a non-invasive system which is able to identify the *X*, *Y* and *Z* position of each vertebra, from the first cervical to the first sacral vertebra. The mechanical equipment was originally planned and built to be applied to pregnant women (Quaresma, 2009). After

Gabriel A., Quaresma C. and Vieira P..
Vertebral Metrics - Automation of a Non-invasive Instrument to Analyse the Spine.
DOI: 10.5220/0005276101500155
In *Proceedings of the International Conference on Biomedical Electronics and Devices* (BIODEVICES-2015), pages 150-155
ISBN: 978-989-758-071-0

an automation process, a semi-automatic prototype was developed. This prototype can be applied in general population. Its setup uses a camera and a laser diode to measure the spatial coordinates of each spinal process. Using an adequate blue marker to identify the spinal processes, the recognition is achieved with software capable of distinguish the prominent blue marks in the skin. However, the time required for data acquisition is about three minutes. Artefacts in measurements are affecting the performance of the system because individuals can not stand still for such a long period of time. This constraint limits the practical use of the equipment. For that reason, the further development of the Vertebral Metrics has become necessary. The aim of this paper is to present a third improved prototype that is being developed. This system will have several differences comparing to the previous prototypes. With the new equipment tests will be faster with an improved resolution.

2 AUTOMATION OF THE VERTEBRAL METRICS

The main purposes of the automation of the Vertebral Metrics are the improvement of the resolution and time required for data acquisition.

For a better understanding of the instrument that is under study the axis system considered will be defined as following: the transversal distance as *X* coordinate, the antero-posterior distance as the *Y* coordinate and the height as *Z* coordinate.

Several modifications will be performed comparing to the existing prototype. The equipment that is being projected will move along the Z direction only. It has been designed to have two video cameras and two UV lights that will be fixed in specific positions. A fluorescent dye will be used to identify the projection of the spinal processes. This dye emits a specific wavelength when exposed to the ultra-violet radiation. Also the triangulation method, that uses a RGB camera and a laser diode, will be replaced by the stereo vision method. The software has to be adapted to perform scans with the new model.

The characteristics of the automated system will be described in the following topics.

2.1 Mechanical System

The design of the mechanical system has been already projected using SolidWorks™ (Figure 1). It is a vertical structure which has a bracket coupled. This bracket consists of two identical video cameras positioned between two ultraviolet lights.

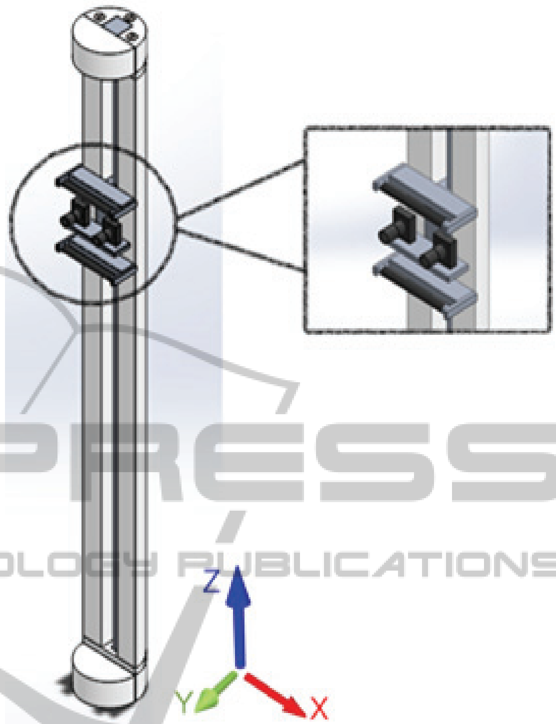

Figure 1: Scheme of the mechanical system.

There are two main goals for the mechanical structure: resolution and speed. The instrument is being constructed based on the following pre-requisites:

- The mechanical apparatus should move all the hardware necessary for the image acquisition in the *Z* direction (up and down).
- Must move *1000 mm* in *30* seconds (*33.3 mm/s*).
- Must have a communication protocol controlled by software.

For the vertical positioner a linear stage will be used. It has a high helix pitch lead screw providing high-speed positioner. The motor will be step-by-step type for precision positioning. As in the previous prototype, the motion and control of the motor will be performed by a microcontroller PIC16F877 from Microchip™. In addition, the microcontroller will also monitor limit switches, control serial RS232 communications and control lights relays.

In terms of RS232 communication a protocol will be developed based on instructions and replies.

Therefore, the microprocessor will only answer and execute commands from the computer.

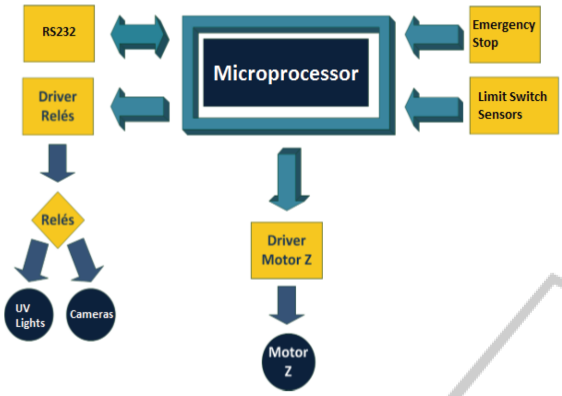

Figure 2: Scheme of the communication system.

2.2 Determination of Distances Using a Stereo Vision System

Stereo vision is a method that provides *3D* perception by means of two different images of the same scene. To develop a stereo vision system some specific elements are required. The geometry of the system is also a relevant concern.

In order to engineer a stereo vision system, two video cameras will be fixed side by side in a horizontal support with parallel optical axes. Both cameras will be equidistant from the middle of the support (Figure 3). This distance has to be studied in order to maximize the performance of the equipment.

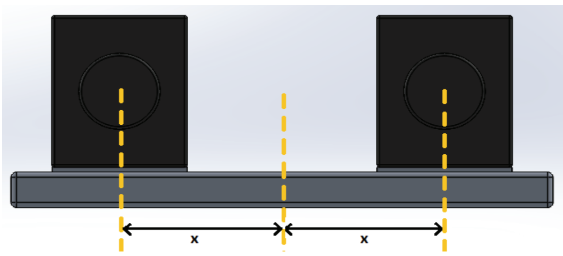

Figure 3: Scheme of the stereo vision system (x0z plane).

The system must have at least *1 mm* of resolution in all directions (*X*, *Y* and *Z*). To achieve the desired resolution several calculations that involve trigonometric equations have been studied in detail. It was concluded that any camera available in the market would be sufficient to identify the *X* and *Z* coordinates. However, powerful cameras are required to assess the *Y* coordinate. The selected cameras are from IDS™, model UI-3480ML. They are monochromatic cameras with 2560x1920 resolution. A lens with *12 mm* of focal distance (Optica Goyo from IDS™) will be coupled to each camera.

Software must be developed in order to determine the spatial position of each spinal process through the stereo vision method. Different approaches of the image processing algorithms are still being studied at this stage of the project.

2.3 Detection of the Spinal Processes

Two programming softwares - Matlab™ and Visual Studio™ - will be used to develop all software including the algorithms to perform the detection of the spinal processes. The image processing algorithms will be implemented in Matlab™ (MATrix LABoratory, a numeric computer environment for programming). Visual Studio™ will be used to define functions for communication with the mechanical equipment as well as the user interface.

Selecting an appropriate marker to identify the patients' skin above the vertex of each the spinal process is the first step required to the development of the image processing algorithms. The marker will be a fluorescent dye. When excited by ultraviolet light this dye emits a well-known wavelength that must be different from the wavelength of the ultraviolet light. Presently, several spectroscopic tests are being performed with multiple dyes in order to choose the most adequate (Figure 4). It is noteworthy that the dyes under study are suitable for skin.

Only wavelengths emitted by the marker will be detected by the cameras. The emission spectrum of the ultraviolet lights (Figure 4c) has a clear peak at 400 nm so the wavelength of the emission peak of the adequate markers must be quite different. By observing all the emission spectrums it was concluded that the dyes *iv* and *v* might be adequate markers (Figure 4g and Figure 4h, respectively) because they emit between *625 nm* and *675 nm*. Spectral tests are still being performed with those two dyes in order to achieve the most appropriate.

Optical filters must be positioned in front of each camera in order to prevent other wavelengths. As the emission wavelength of the *iv* and *v* dyes comprises the red region of the visible spectrum, the red component of the RGB image was used to simulate the filter (Figure 4b). Both dyes are completely distinguishable from the skin, therefore, the positioning of the filters in front of the cameras may simplify dramatically the definition of the algorithms.

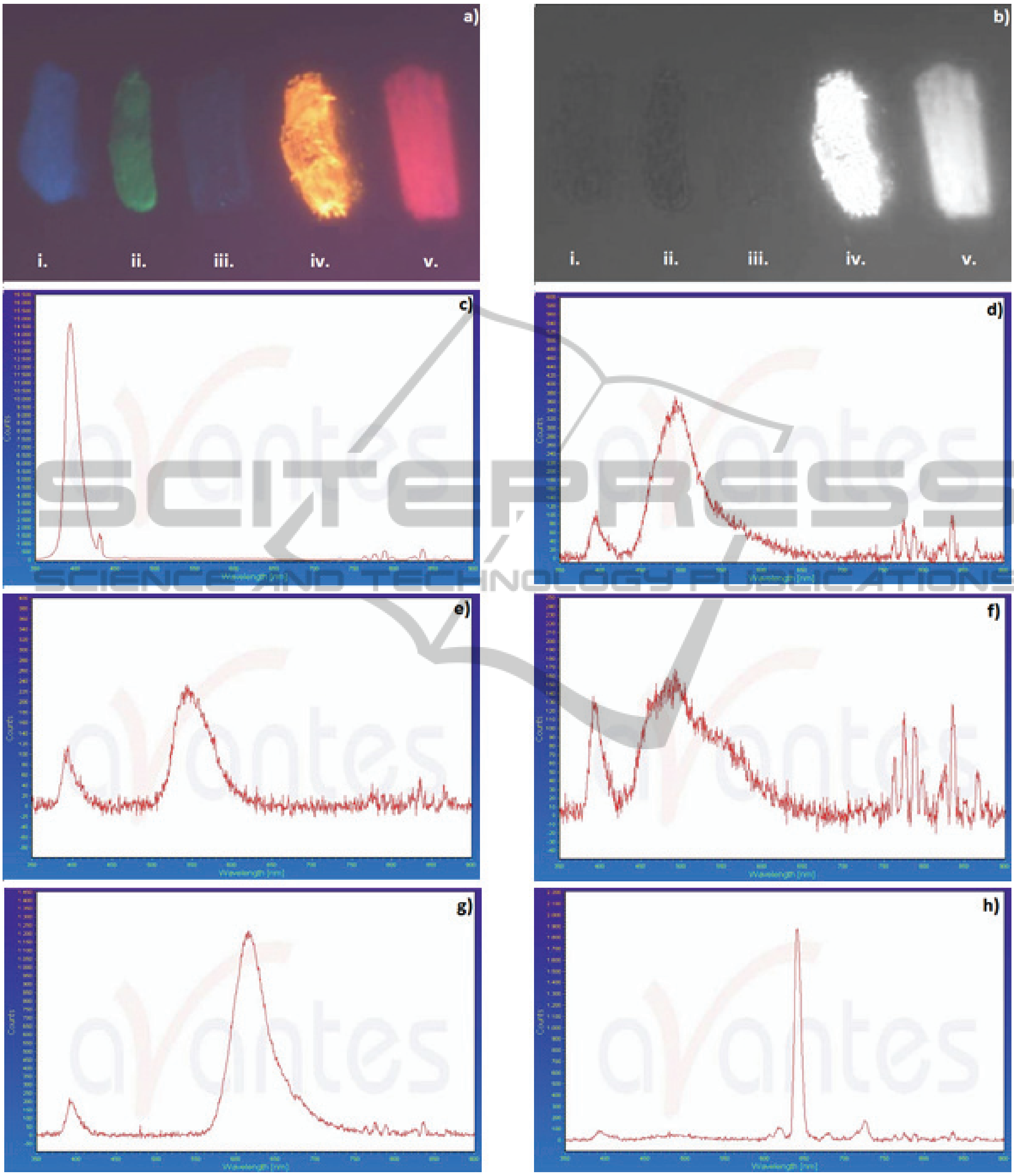

Figure 4: Study of fluorescent dyes. a) RGB picture of the fluorescent dyes in skin; b) Red component of the previous image; c) Emission spectrum of the UV lights; d) Emission spectrum of the first dye (i); e) Emission spectrum of the second dye (ii); f) Emission spectrum of the third dye (iii); g) Emission spectrum of the fourth dye (iv); h) Emission spectrum of the fifth dye (v).

While the vertebral metrics equipment is operating the data acquisition process will be simple. In the beginning of each scan the physician has to move the mechanical system until the first sacral vertebra is seen by the cameras. An intuitive interface is being developed to assist the positioning. After the physician orders the mechanical system begins its upward movement. The software has a cyclical behaviour wherein the cameras acquire a pair of images simultaneously every *20 ms*. Each pair of images is saved in memory and analysed by the image processing algorithms when the scan is completed. It is noteworthy that data acquisition will be achieved in such a short period of time – about *30* seconds - because the image processing will be performed after a full scan of the spine.

The start position of the mechanical system, its vertical speed and the time between the acquisition of each pair of images as well as the stereo vision method are essential to determine the spatial position of the vertebras. The physician has the possibility of save data acquired in a single file. By running this file in a specific software the *3D* reconstruction of the spinal column can be observed. An example that uses data acquired with the second prototype is presented in Figure 5.

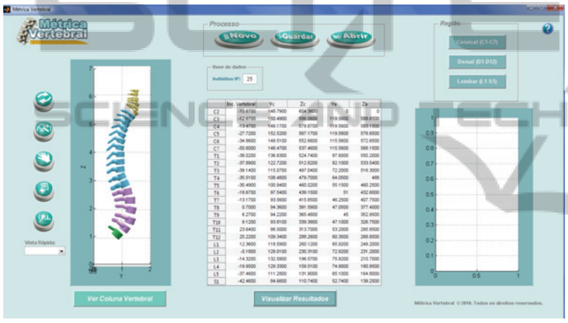

Figure 5: *3D* reconstruction of the spinal column.

3 CONCLUSIONS

The present study will contribute to the automation of a non-invasive equipment that is a complete innovation in health – the Vertebral Metrics. Throughout this article, the characteristics of the new prototype of the Vertebral Metrics were described. At this moment a few steps were already taken: the scheme of the new prototype was drawn, the characteristics of the cameras were determined through trigonometric equations and studies with fluorescent dyes are being performed. The future of the project will comprise the implementation of software, image processing algorithms and instrumentation. Furthermore, the equipment must be validated. Tests in people with biomechanical changes of the spine will be performed with Vertebral Metrics and compared with X-ray (the gold standard) in order to prove that it is reliable system.

The differences between the previous prototypes and the system that is being built will be particularly relevant regarding the acquisition time required to collect the individuals data. The stereo vision method will improve the resolution and the accuracy of the equipment. As data acquisition will be performed faster it will also allow the analysis of the postural adjustments. However, the patient's skin above the vertex of the spinal processes still needs to be marked by the physician.

Due to its non-invasive characteristics the Vertebral Metrics will be a powerful tool to evaluate the spinal column. In a few seconds the new equipment will provide a comprehensive overview of the spine as it will perform a complete scan in about 30 seconds. Furthermore, it will became available a three dimensional analysis of the vertex of the spinal processes.

This unique and already patented device will avoid unnecessary invasive methodologies as well as qualified staff for screening and prevention of spinal disorders because it will allow repeated scans without causing damage to the individuals. It may be used in different contexts such as ambulatory public and private (healthcare centre / doctor's office), hospital and as a potential screening device for back pain in the general population. Using the Vertebral Metrics will also became available the definition of the most appropriate intervention methodologies to each particular clinical case.

ACKNOWLEDGEMENTS

The authors would like to acknowledge *NGNS-Ingenious Solutions* for the support provided.

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