A System for Analysis of the 3D Mandibular Movement using Magnetic Sensors and Neuronal Networks

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Abstract. In Dental Medicine, the study of the mandibular movement has an important role in the development of oral rehabilitation treatments, because it allows to determine if exists or not pathologies in the temporomandibular joints and helps the definition of adequate treatment plans. In this paper, is presented the development of a new system for the acquisition of the 3D mandibular movement. A common facial arc used in Dental Medicine was adapted as main support structure, and electromagnetic sensors were used to acquire the movement. To visualize and analyze in a personal computer the movement acquired, it was developed a computational application using *LabVIEW*. In this work neural networks were employed to transform in cartesian coordinates the electrical signals obtained from the electromagnetic sensors used.

1 Introduction

The human mandible and the temporomandibular joint form an interest and complex biomechanical system that performs several functions, and have the capacity to make high forces with great precision. The peculiar construction of the temporomandibular joint allows the mandible to move in six degrees of freedom. In Dental Medicine is essential to know the mandibular cinematic to simulate the temporomandibular joints, to position teeth moulds in articulators, and to reproduce the mandibular movements in order to insure a satisfactory occlusion.

Enciso and Hugger [1, 2] describe the *Jaw Motion Analyzer* and Pröschel [3] presents the *ARCUSdigma*. These are two commercial systems for the acquisition of the 3D mandibular movement that use ultrasonic sensors to acquire the trajectory of the incisive point. Leader [4], Mesnard [5] and Kinuta [6] use optical systems to record the same movement, and Garcia [7] describe the *K7 Evaluation System* which is a system that uses electromagnetic sensors for the same purpose.

Currently, both commercial and custom made devices are considered very expensive and difficult to use in common clinical situations, [8].Considering these disad-

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vantages, it was developed a new system for the acquisition, visualization and analysis of the 3D mandibular movement that is economical, easy to use and sufficiently precise, [8].

The development of the new system was divided in three phases: the choice of the technology to use in the acquisition of the movement, the conception of the support structure for the sensors used, and the development of a computational application to visualize and analyze the 3D data obtained by using a personal computer.

In the next section is described the prototype developed for acquired the 3D mandibular movement. Next, is presented the computational application developed to visualize and analyze the movement acquired and the usage of neural networks to transform the electric signals of the sensors in 3D cartesian coordinates. Some conclusions and perspectives of future work are presented in the fourth, and last, section of the paper.

2 System's Development

The development of our prototype system began with the choice of the technology to use in the 3D mandibular movement acquisition, because the device support structure would strongly depend on it. Electromagnetic sensors were used to measure the magnetic field created by a small magnet, Fig. 1, placed inside the patient's mouth (near to the incise point). The magnetic field of the used magnet is 760 Gauss.

Fig. 1. Magnet used in our system for the acquisition of the 3D mandibular movement.

The selected sensors were the *AA002-02* from *NVE Corporation*, Fig. 2. These sensors were selected due to their low price, low current consumption, small size (5.99 x 4.90 x 1.55 mm) and excellent sensitivity.

As the *AA002-02* sensors are sensitive in one direction in the plane of the integrated circuit it was necessary to use three sensors in order to acquire the 3D movement of the mandible. Thus, two circuit boards were specially developed in order to mount the sensors perpendicularly and to handle them more easily.

After choosing the technology to use in the movement acquisition, it was necessary to design the support structure for our acquisition system. Instead of creating a new device structure, a common facial arc used in Dental Medicine was adapted as the main support structure. Among the commercial facial arcs the chosen one was the *Arcus* from *Kavo,* Fig. 3.

Fig. 2. Sensors used in our prototype system: *AA002-02* from *NVE Corporation.*

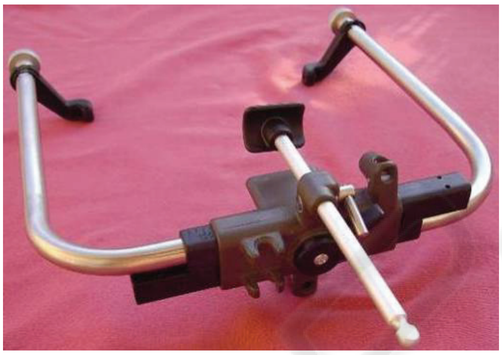

Fig. 3. Facial arc *Arcus* from *Kavo* used as the main support system of our prototype system.

As the selected arc was primary conceived to make static measurements, the first step in its adaptation was the redesign of the pieces that could difficult the dynamic measurement or harm the patient. Thus, the auricular pieces were redesigned, Fig. 4.

Fig. 4. Redesigned auricular pieces materialized by rapid prototyping.

For the development of the sensors support was taken in consideration that it should meet the following requirements: to be adaptable to the facial arc used; to accommodate the two circuit boards designed, and the three electromagnetic sensors used for the movement acquisition; and to be light.

To attach the sensors support to the facial arc it was used an already existing groove in the same; then, to avoid the translation and the rotation of the support relatively to the facial arc, it was created a notch in the sensors support, Fig. 5. The end of the sensors support was enlarged to accommodate the connection between the wires coming from the sensors and the data acquisition's box.

Fig. 5. The developed support for the sensors used materialized by rapid prototyping.

The two circuit boards developed are mounted in the sensors support by pressure; the access to the sensors boards is carried through a sliding cover, which has a hole for a led that indicates if the acquisition system is turned *on* or *off*, Fig. 6 and 7.

Fig. 6. Detail of the circuit boards mounted in the support developed for the sensors used.

For the acquisition of the sensors signals it was used a data acquisition device (*DAQ*) with plug-and-play *USB* connectivity, the *NI USB-6008* model from *National Instruments*. The *NI USB-6008* is light, small, has a low price and is easy to use. It has four differential analog channels (or eight single ended), 12 bit resolution, acquisition rate up to 48 kS/s and can power external components as well. In this work it was the differential mode in order to reduce the electrical noise.

Fig. 7. Sensors support developed and the magnet used in the acquisition of the 3D mandibular movement.

In spite the *DAQ* selected could be used to directly power the electromagnetic sensors, as already referred, it was used an external power supply for that purpose instead. The power supply *RS7694* from *RS Amidata* has +15V output voltage which increases by three the output signal of the magnetic sensors.

Fig. 8 shows the *DAQ* and the power supply used in our prototype system for the acquisition of the 3D mandibular movement.

Fig. 8. Acquisition box with the *DAQ* and the power source used in our acquisition system.

3 Computational Application

To make easy the acquisition and analysis of the 3D mandibular movement using a personal computer, it was build a new computational application with an adequate graphical interface using the developing tool *LabVIEW* from *National Instruments*.

Figs. 9 and 10 show the interface of the developed application for our prototype system. In the upper part of the interface designed, the users can write the patient's personal data: the name, the age, the sex and the missing teeth. The control buttons of the application (start "Começar", stop "Parar", report "Relatório" and exit "Fechar") are placed in the lower part of the interface.

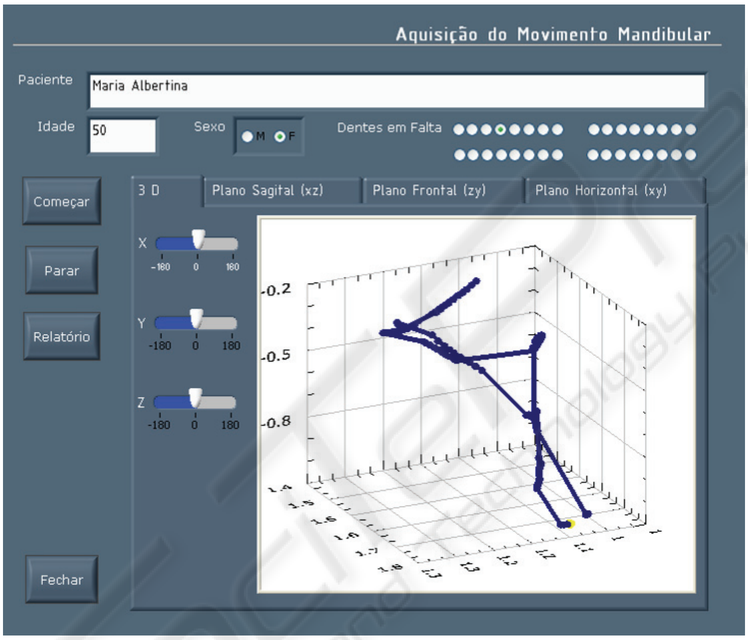

Fig. 9. Computational application developed for the 3D mandibular movement acquisition and analysis: 3D graphic.

The results obtained are displayed using four graphics: one with the 3D movement (Fig. 9), and three 2D graphics with the projections of the same movement in the sagital (Fig. 10), frontal and horizontal plans. The user can rotate and zoom the 3D graphic.

By pressing the button "Relatório" a report for the current medical exam is generated and then the user can print or save it, Fig. 11.

To know the 3D trajectory of the magnet, placed inside the patient's mouth, was necessary to convert the output voltage of the three electromagnetic sensors used in 3D cartesian coordinates.

While testing the acquisition system developed, was verified that moving the magnet in one direction the output voltage would vary simultaneously for the three sensors used; that is, to each position in space (coordinates x, y and z) correspond a set of three voltages. To solve this problem, a neural networks approach was used.

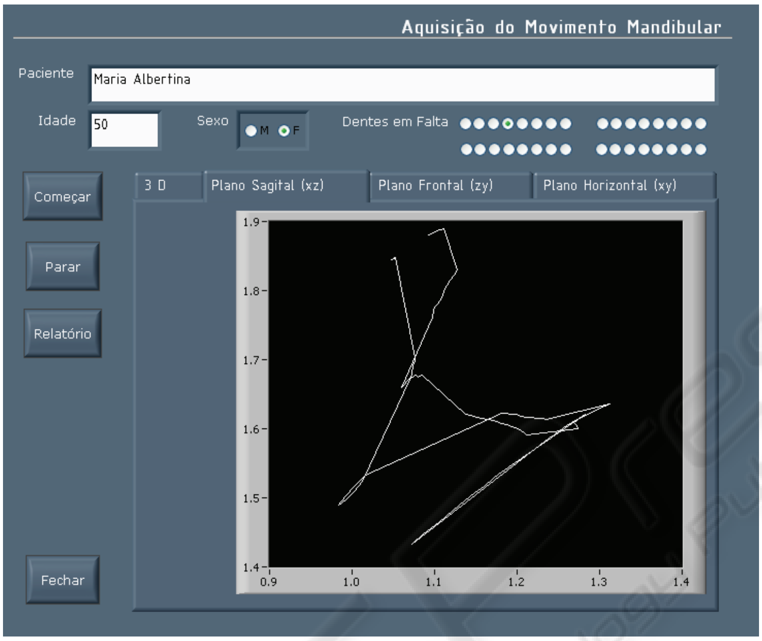

Fig. 10. Computational application developed for the 3D mandibular movement acquisition and analysis: 2D graphic in the sagital plane.

Neural networks are inspired by biological nervous systems; they are composed of simple elements operating in parallel and can be trained to perform a particular function by adjusting the values of the connections (weights) between elements, [9, 10].

In this work radial basis networks were used, because they are trained more quickly, and is possible to interpret the contribution of each unit in the global behavior of the net, because each layer is only active in a limited zone of the entry space [10].

The network used is composed by two layers: a hidden radial basis layer of *S1* neurons, and an output linear layer of *S2* neurons, Fig. 12. The transfer functions considered in the neural network used are plotted in Fig. 13.

As generally the mandibular movement doesn't exceed the limits defined by a parallelepiped with 70 mm height, 40 mm length and 40 mm depth, it was registered the output voltage of each electromagnetic sensor at several calibration points. These points' coordinates and the associated three voltages were then used as "inputs" and "targets" to create and train the network used in the conversion voltages/coordinates.

The neural network built was integrated in our computational application using the *LabVIEW* as well.

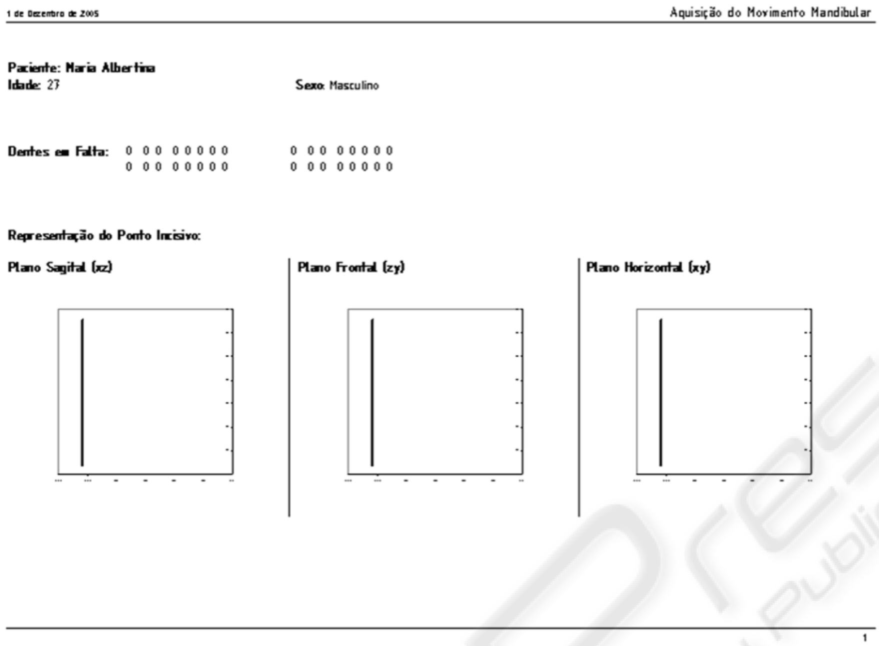

Fig. 11. Example of a measurement report generated using the computational application developed for our system.

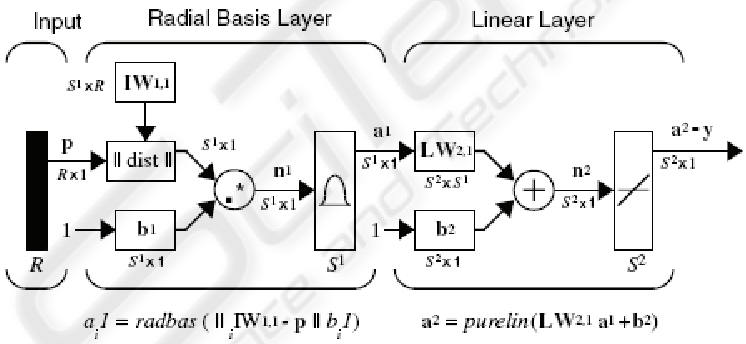

Fig. 12. Neural network used in our system for the conversion voltages/coordinates (adapted from [9]).

In Fig. 14 is presented our prototype system for 3D mandibular movement acquisition and analysis. The usage of the developed system is easy and comfortable for patients and medical doctors.

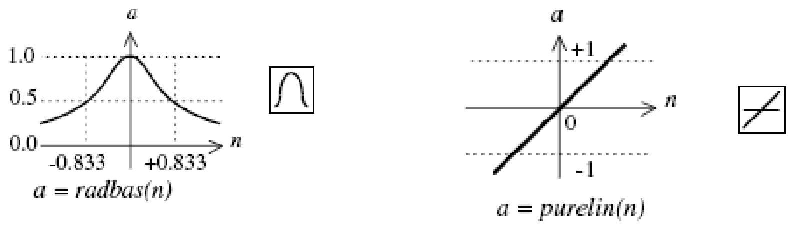

Fig. 13. Transfer functions used in the neural network adopted in our prototype system for the conversion voltages/coordinates (adapted from [9]).

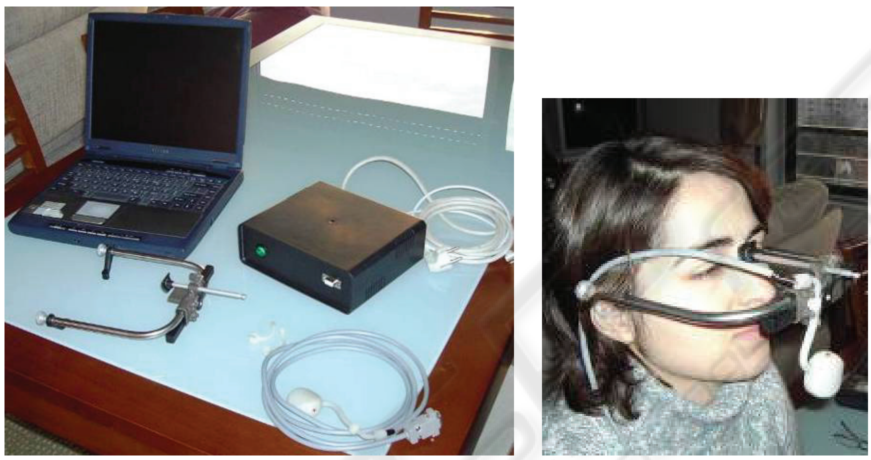

Fig. 14. Our prototype system for 3D mandibular movement acquisition and analysis and its usage.

4 Conclusions and Future Work

The aim of this work was the developing of a new prototype system for the acquisition, visualization and analysis of the 3D mandibular movement, economical, easy to use and comfortable to patients.

To acquire the 3D trajectory of the incise point were used electromagnetic sensors, because they are economical and don't impose any restrictions to the acquisition process. The magnetic field is created by a small magnet placed inside the patient's mouth, near to the incise point.

A facial arc common used in Dental Medicine was adapted as the main support structure of our acquisition system. Some pieces of this arc were redesigned for a more comfortable patient's usage, and it was designed a specific support for the three magnetic sensors used in the movement acquisition.

To visualize and analyze the acquired signals in a personal computer it was created, using the developing tool *LabVIEW,* a computational application with a graphical interface with which the operator can register the patient's personal data also; with the same application, its possible to create a report with the patient's data and the results of the medical exam as well. To convert the electrical signals obtained by the three electromagnetic sensors in distance a neural network was used.

The prototype system developed has adequate precision and can be produced at low price. So we think that it is a good help for medical doctors to detect and define good treatment plans for problems of dental occlusion.

As some possible future tasks we can enumerate: for clinical validation, the use of the developed prototype system in numerous medical exams; the study of the employment of more complex neural networks, to transform the electrical signals of the three electromagnetic sensors used in 3D cartesian coordinates; to export the exam data to some standard articulators systems; and the animation of virtual mandibles using the movement acquired by our system.

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