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A DIGITAL SYSTEM FOR MEASUREMENTS IN GYPSUM MOLDS FOR ORTHODONTICS

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Abstract. *In this article an innovative digital system able to measure the surface contour of maxillae gypsum molds is presented. This system was conceived to automate processes such as data acquisition, data manipulation, image visualization and evaluation of results from data analysis. Its main component is a digital device formed by an articulated mechanical arm with three links and revolute joints, each one associated to an incremental encoder. Each sensor is interfaced to a data acquisition card located in a microcomputer and a dedicated program is responsible to the variables manipulation. The average resolution of the measuring system is less than 0.4 mm. The measurement procedure can be summarized as follows: the movement of the mechanical arm in contact with the gypsum mold generates digital data from sensors to the computer, which are converted into Cartesian coordinates according to Denavit-Hartemberg parameters. Then, the image of the mold contour is showed in the computer screen so that the user can visualize the results of the data acquisition being analyzed and decide rather they are ready or not to be registered in a file. Statistics is used to evaluate data from acquired curves. Once the curves are obtained, the ultimate analysis such as relative linear and angular displacements at predefined points of a curve or superimposed curves can be evaluated.The digital system was used in more than 3000 models in the USA with success.*

Keywords: *measurement device, orthodontics, gypsum mold, mechatronics*

1. Introduction

The first evidences on systematically dental treatment in human mouth appeared in 400 A.C. circa. Mr. Pierre Fauchard - a French dentist - is considered to be the first person to initiate a scientific approach to this topic, due to the publication of the book “Dentist Surgeon”, in 1728.

The term Orthodontics was created by Le Foulon - a French dentist - in 1839 and is a composition of two Greek words: “Orthos”, meaning correct and “Dons”, meaning tooth. Orthodontics is a specialization concerning the study of how to prevent and use the best means to correct the dental malocclusions, or incorrect bite.

A definition to occlusion is the alignment and spacing of the maxilla and mandible when the mouth is closed during a mastication motion. A normal shape of the dental arch is necessary to obtain a symmetric positioning of the teeth, so that no occlusion problems occur (Fig. 1). These problems can have influence on personal esthetics, disturb the mastication and muscle systems, and in some cases reduce the capability of speech (Moyoyers, R.E., 1991).

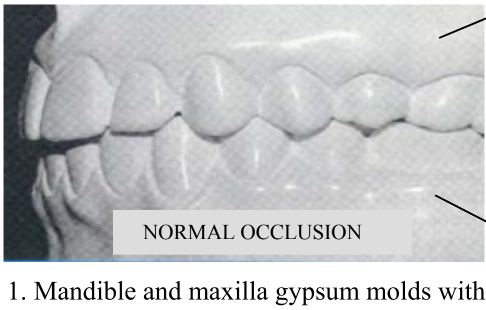


Figure 1. Mandible and maxilla gypsum molds with normal occlusion.

The concept of teeth symmetry in orthodontics considers the human patterns, so it should be used as a synonym to teeth equilibrium. The shape of the dental arch depends on the genetic code of each person, then, in normal conditions the teeth will grow in genetically determined locations (Sinclair, P., Little, R., 1985)

According to Palmer's notation the mouth is divided into four parts called quadrants: the upper left quadrant, the upper right quadrant, the lower left quadrant, and the lower right quadrant as illustrated in the Fig. 2 (Massel, R., 1999).

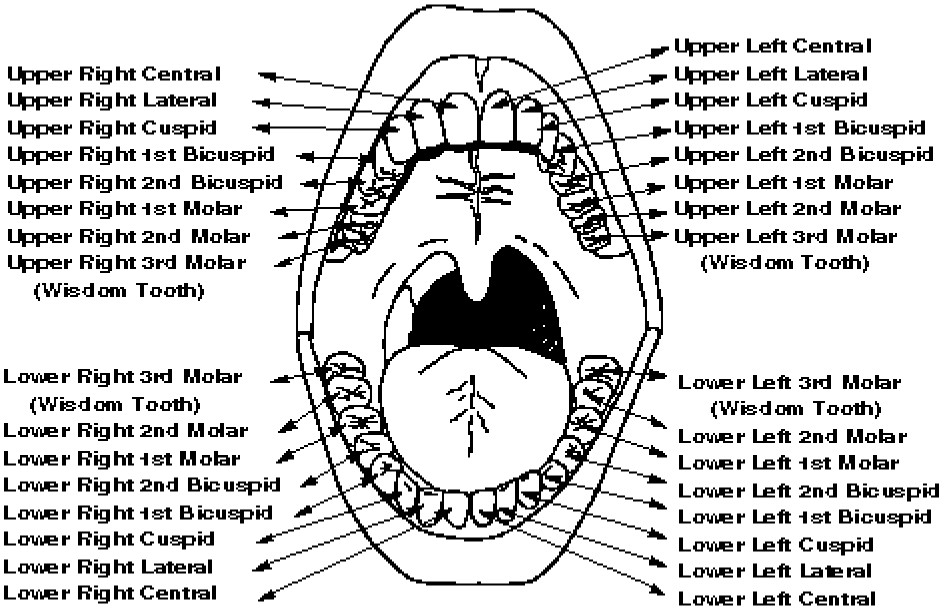


Figure 2. Names of individual teeth.

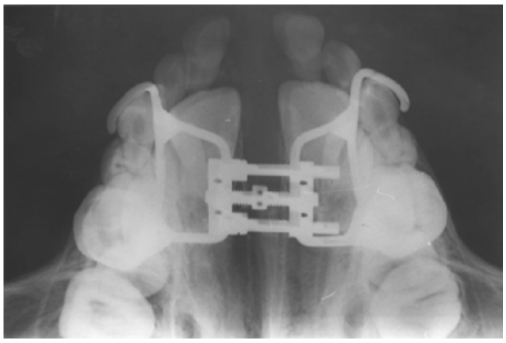
2. Malocclusion treatments

2.1. Rapid maxillary expansion

There are many forms of malocclusion treatments in orthodontics and one of the most common is the method of rapid maxillary expansion (RME). This treatment is used in deficiencies such as transverse maxillary atresia, characterized by a narrow palate, resulting in misalignments between maxilla and mandible.

The RME method consists in using a palatal expander to gradually move the previously ruptured maxilla, until the normal shape of the dental arch is acchieved. Palatal expanders such as Haas, Hirax, Mc Namara and Schwarz use a screw as the elementary component. The Haas expander is presented in Fig. 3a and 3b (Haas, A., 1980).

(a)



(b)

Figure 3. Haas expander: (a) in a gypsum mold, (b) in the pacient maxilla.

2.2. Gypsum molds

Maxillae gypsum molds are necessary to establish the planning of treatment, case-studies comparisons and monitoring during all phases of a RME treatment. The gypsum mold can be considered as a database of the orthodontic conditions of a person maxilla or mandible, since many parameters can be extracted from it. The success of a long-term treatment depends basically on these gypsum molds.

The results of a case analysis with RME method are the study of the historical series of gypsum molds made during all treatment phases.

The main parameters of a gypsum mold used to evaluate a phase are related to linear and angular parameters obtained at transverse planes denominated intermolar – containing the first molars teeth –, and intercanine – containing the first canines or cuspids teeth -. In Fig. 4a these planes are indicated.

For each plane are defined five point varying from A1 to A5, which will determine all necessary linear and angular parameters to the analysis (Fig. 4b).

In the case of intermolar plane, A1 and A5 are choosen at the interface between first molars and mandible or maxilla. They define the distance BMBL (Bi-Molar Bone Lenght). A3 correspond to the lower point at mandible or maxilla. A2 and A4 are located 2 mm above point A3, defining the distance BMLL (Bi-Molar Lower Lenght).

The angular parameter α is denominated base angle and measures the angular variation of lines A1-A2 and A5-A4 along the treatment.

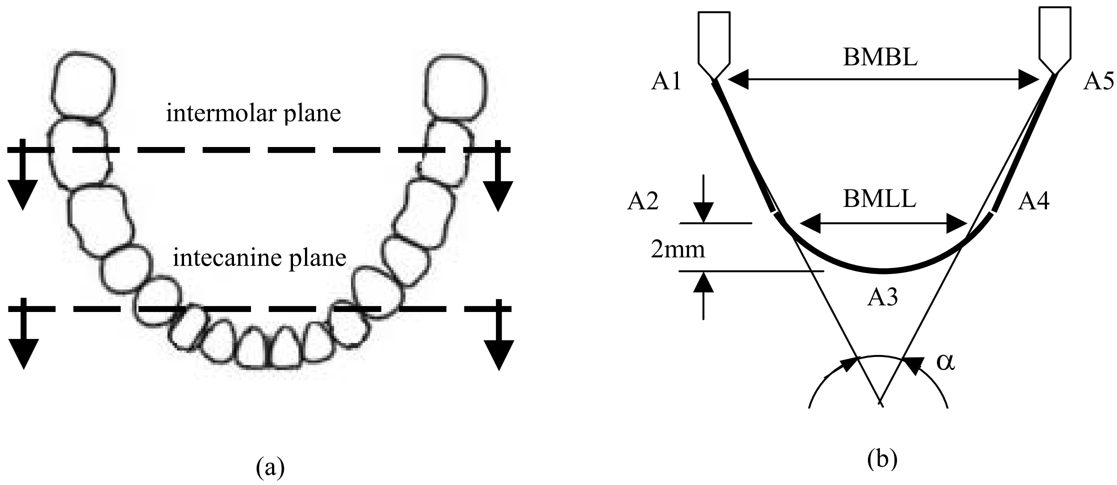


Figure 4. (a) Intermolar and intercanine transversal planes. (b) Gypsum mold parameters.

2.3. Measuring devices

The usual measuring procedure to get gypsum mold parameters is based on data acquisition from linear devices such as compass and caliper. The right choice of location points depends on the operator ability, so measuring repeatability is poor. Data deviations will result in final calculation errors.

An ink registration device based on pantograph mechanism is also used to draw the intermolar and intercanine transversal planes in a sheet of paper, so that the parameters can be evaluated.

Admissible linear resolution is ± 0.5 mm, while angular resolution is ± 3 degrees.

3. Digital system for gypsum molds

3.1. General aspects

The proposed digital system for gypsum molds is able to make digital data measurements of the surface contour of maxilla or mandible gypsum molds.

This system is manually operated and was conceived to increase the feasibility and performance of the operator and automate processes such as data acquisition, data manipulation, image visualization and evaluation of results from data analysis. It is suitable for the intermolar and intercanine transversal planes parameters calculations.

Basically, the system elements are a mechanical arm with sensors, a microcomputer, and data acquisition and manipulation programs. These elements are shown in Fig. 5.

The measurement procedure can be separated in two complementary steps, as presented in Fig. 6.

The first step is the data acquisition procedure and consists on the manual motion of the mechanical arm along a gypsum mold by an operator and a DOS program to capture and transfer the acquired points to a binary database file. This step is related to on site tasks.

The second step concerns offline tasks such as the data manipulation and analysis of the database file previously created in step one.

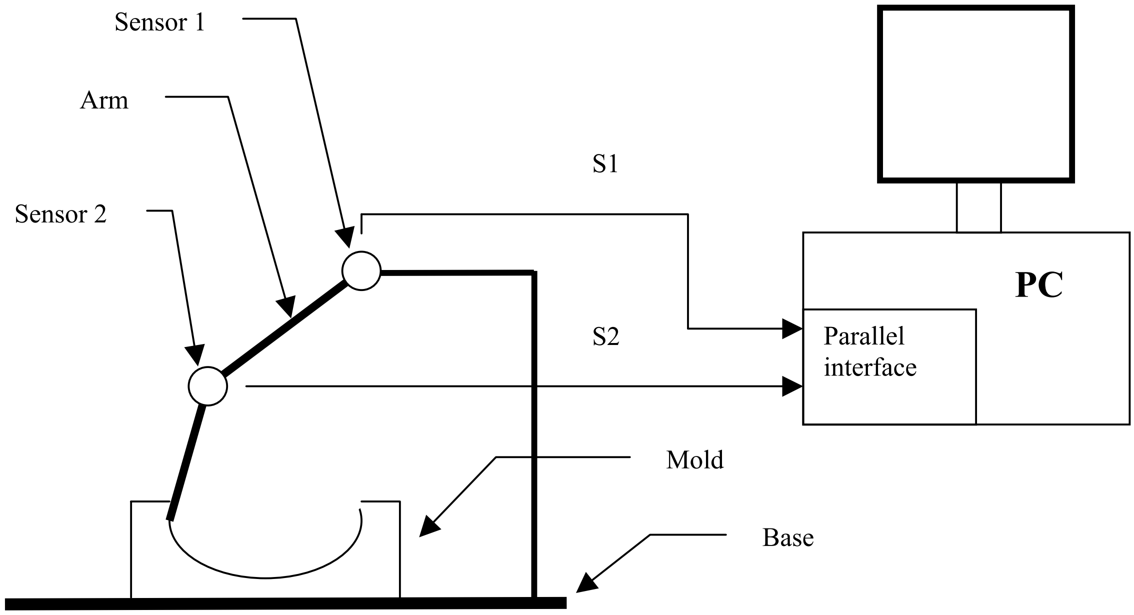


Figure 5. Elements of the Digital System for Gypsum Mold measurement.

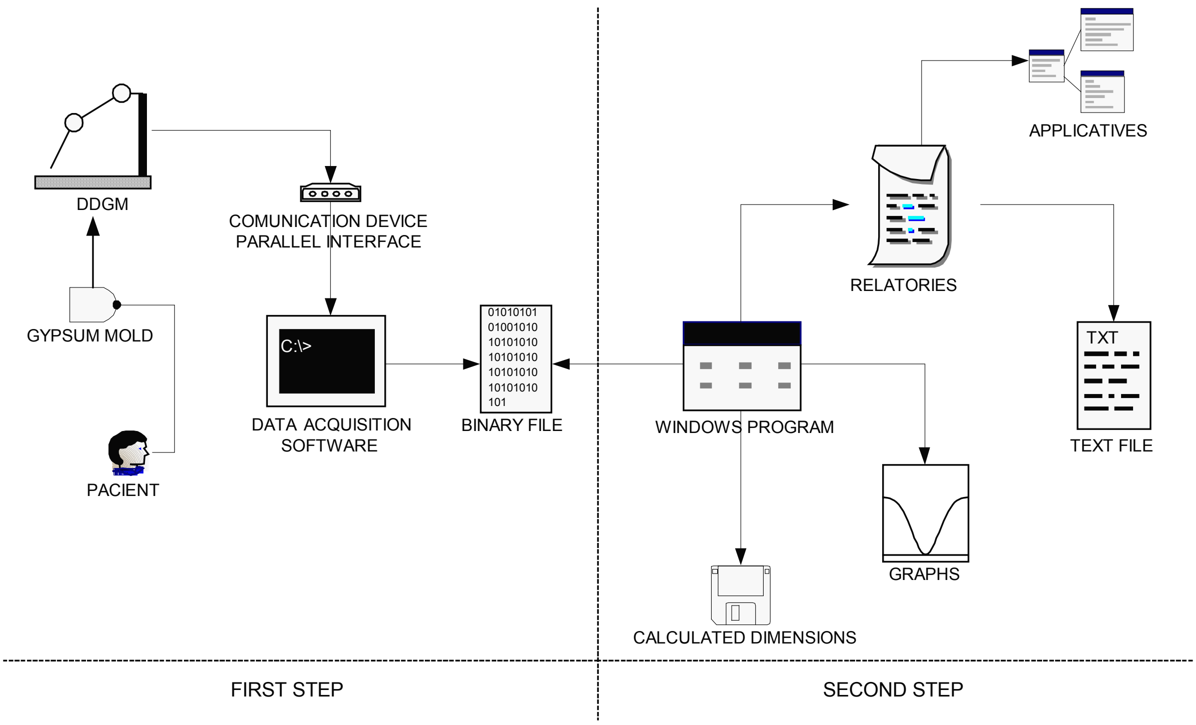


Figure 6. Data acquisition and manipulation procedures.

3.2. Digital Device for Gypsum Molds

A digital device - DDGM (Digital Device for Gypsum Molds) – is the main element of the measuring system. It is an articulated rigid mechanical arm with three links, two revolute joints and a counterweight.

A metallic probe with a spherical tip of 1mm diameter is connected at one of the DDGM extremities, in order to provide a direct and precise contact with the gypsum mold. The other DDGM extremity is rigidly connected to a mechanical structure.

Each joint is associated to an angular sensor (incremental encoder), providing digital inputs to the parallel port of a microcomputer or laptop, when the operator moves the DDGM along a gypsum mold. A photo of the DDGM is presented in Fig. 7.

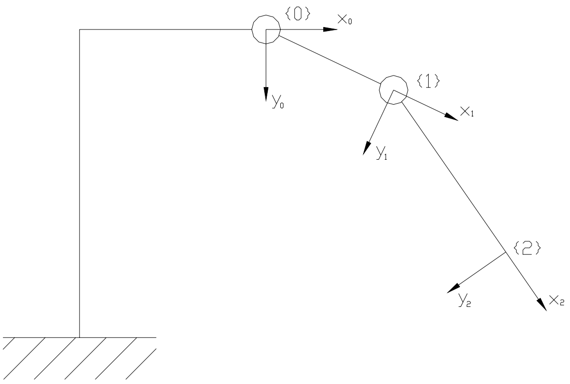
Figure 7. DDGM and a gypsum mold.

A dedicated DOS program is responsible to joint variables acquisition and conversion into Cartesian coordinates, through direct kinematics relations. Then, the image of the mold contour is showed in the computer screen so that the user can visualize the results of the data acquisition being analyzed and decide rather they are ready or not to be registered in the database file.

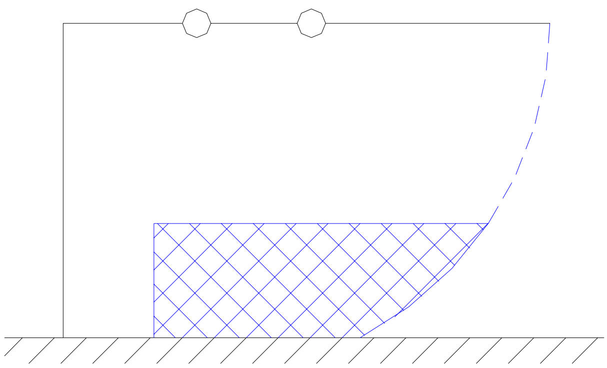
3.2.1. Kinematics model

The DDGM direct kinematics model can be expressed by a homogeneous transformation matrix, which indicates the rotation and position of the DDGM end-point in relation to the system reference coordinate frames {0}.

Denavit-Hartenberg parameters are used to obtain the homogeneous transformation matrix (Sciavicco, L., Siciliano, B., 1995). For the modeled planar arm with 2 degrees-of-freedom (Fig. 8a), these parameters are indicated in Tab. 1.



(a)



(b)

Figure 8. (a) System reference coordinate frames. (b) DDGM operational workspace.

Table 1. Denavit-Hartemberg parameters.

Link	α_i	a_i	d_i	θ_i
1	0	l_1	0	θ_1
2	0	l_2	0	θ_2

The resulting homogeneous transformation matrix is presented in Eq. (1).

$$ {}^{0}T_2 = {}^{0}T_1 \cdot {}^{1}T_2 = \begin{bmatrix} C_{12} & -S_{12} & 0 & l_1C_1 + l_2C_{12} \\ S_{12} & C_{12} & 0 & l_1S_1 + l_2S_{12} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (1) $$

$$ where: \quad C_{12} = Cos(\theta_1 + \theta_2) \quad e \quad S_{12} = Sen(\theta_1 + \theta_2) $$

3.2.2. Uncertainty analysis:

The Cartesian coordinate (x , y) of the DDGM contact point at the gypsum mold is given by the first two terms of the 4th column in the homogeneous transformation matrix, equation 1. Both values are function of the parameters l_1, l_2, θ_1 and θ_2.

The positioning deviation of a point (x, y) depends on the uncertainties related to these parameters. For example, the positioning deviation of coordinate x is calculated according to the Eq. (2) (Holman, J.P., 1989).

$$ w_x = \left[\left(\frac{\partial x}{\partial l_1} \cdot \Delta l_1 \right)^2 + \left(\frac{\partial x}{\partial l_2} \cdot \Delta l_2 \right)^2 + \left(\frac{\partial x}{\partial \theta_1} \cdot \Delta \theta_1 \right)^2 + \left(\frac{\partial x}{\partial \theta_2} \cdot \Delta \theta_2 \right)^2 \right]^{1/2} \qquad (2) $$

where W_x is the uncertainty of x. A similar equation can be used to y coordinate to achieve W_y.

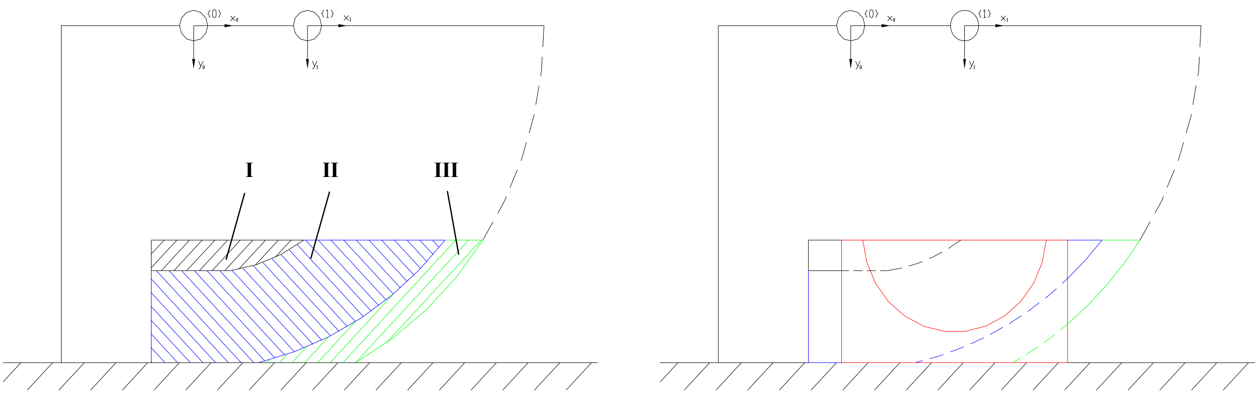
The value of an absolute error for the point is here defined as Eq. (3).

$$ W = \sqrt{(w_x)^2 + (w_y)^2} \qquad (3) $$

The angular uncertainty is related to the encoder resolution. Each joint has an incremental encoder with 512 points/revolution, and this value can be multiplied four times by the algorithm that makes the digital conversion from the sensors. Then, the angular uncertainties $\Delta\theta_1$ and $\Delta\theta_2$ are considered to be $2\pi/2048 \approx 0.003$ rad.

In the case of linear parameters l_1 and l_2, an electronic microscope Aus JENA of 0.001 mm resolution was used to establish the uncertainties. After some measurements the obtained value for both parameters was 0.002 mm.

A discretization of 1067 points was implemented with the software Mathematica® to calculate the error density diagram around the workspace of the DDGM and mold system. Figures 9(a) and 9(b) present the values of W in the operational workspace, according to the following regions: (I) W<0.35, (II) 0.35<W<0.42, and (III) W>0.42. In tab. 2 is indicated the variation range of the uncertainty W.



(a) (b)

Figure 9. (a) Error density of W in regions I, II and III of the operational workspace. (b) Mold within DDGM.

Table 2. Variation range of the uncertainty W.

$W_{mín}$	$W_{máx}$	W_{med}
0,328	0,449	0,392

3.2.3. Manufacturing deviations

Tests in the prototype were performed, so that the angular parallelism deviation in rotation axis {0} and {1} is 0.25 degrees. The deviation of alignment in the same axis in relation to its orthogonal axis is 0.09 degrees.

These deviations do not present variations during the use of DDGM and can be neglected in the error analysis.

3.3. Data acquisition operational procedure

The data acquisition procedure consists on the following sequence of operations, according to Fig. 10:
a) enter the DOS program.
b) DDGM at home configuration to obtain zero reference.
c) operator defines a database filename at the DOS program.
d) positioning of the gypsum mold.
e) operator moves the DDGM to contact the initial point at the gypsum mold .
f) operator sends a command to the computer to start the acquisition.
g) operator moves the DDGM arm along the gypsum mold.
h) operator sends a command to the computer to stop the acquisition.
i) DDGM at home configuration .
j) gypsum mold is removed.
k) operator sends a command to the computer to create the database file.

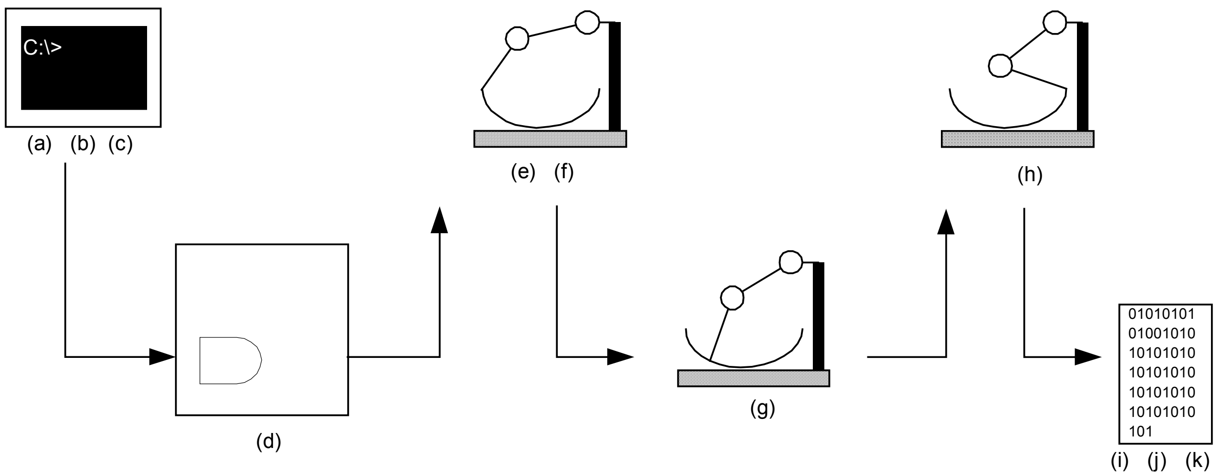


Figure 10. Data acquisition sequence.

3.4. Data manipulation and analysis procedure

A program Windows was developed in order to automate the processes of data acquisition, data manipulation, and calculation, image visualization and evaluation of results from data analysis. The program interface screen is presented in Fig. 11.

Statistics is extensively used to evaluate data from acquired curves. Once the curves are obtained, the ultimate analysis on parameters mentioned in item 2.2 such as BMBL, BMLL and base angle of a curve or superimposed curves can be evaluated. The Pearson coefficient is commonly used in orthodontic analysis to correlate these data.

4. Conclusions

The digital system for measuring gypsum molds was developed by the Robotics Laboratory (LabRob) COPPE/UFRJ team to help Dr. Marcelo Arruda in his PhD. research. He needed a measurement system able to make digital data measurements of the surface contour of maxilla or mandible gypsum molds, in a short time, since he had few days to consult a database of gypsum molds in a Laboratory located in USA.

The innovative concept of the digital measuring system had some advantages such as: simplification of operations, low weight, very easy portability, good resolution (average resolution within the operational workspace is less than 0.4 mm), good repeatability and easy connection with laptops or microcomputers.

Besides, data acquisition and manipulation procedures were enormously simplified and the necessary time to perform these procedures was reduced by a factor of 10, according to the user. A better pattern for gypsum molds was achieved.

In 2003 the digital system for measuring gypsum molds was used by Dr. Marcelo Arruda to evaluate more than 3000 models in three days at Dr. Andrew J. Haas Laboratory, in Chicago, USA. Later, all data were analyzed according to the procedures here presented. The on site and offline tasks were performed with success.

In 2004 this project received the ABCM-EMBRAER 2004 prize in undergraduate category.

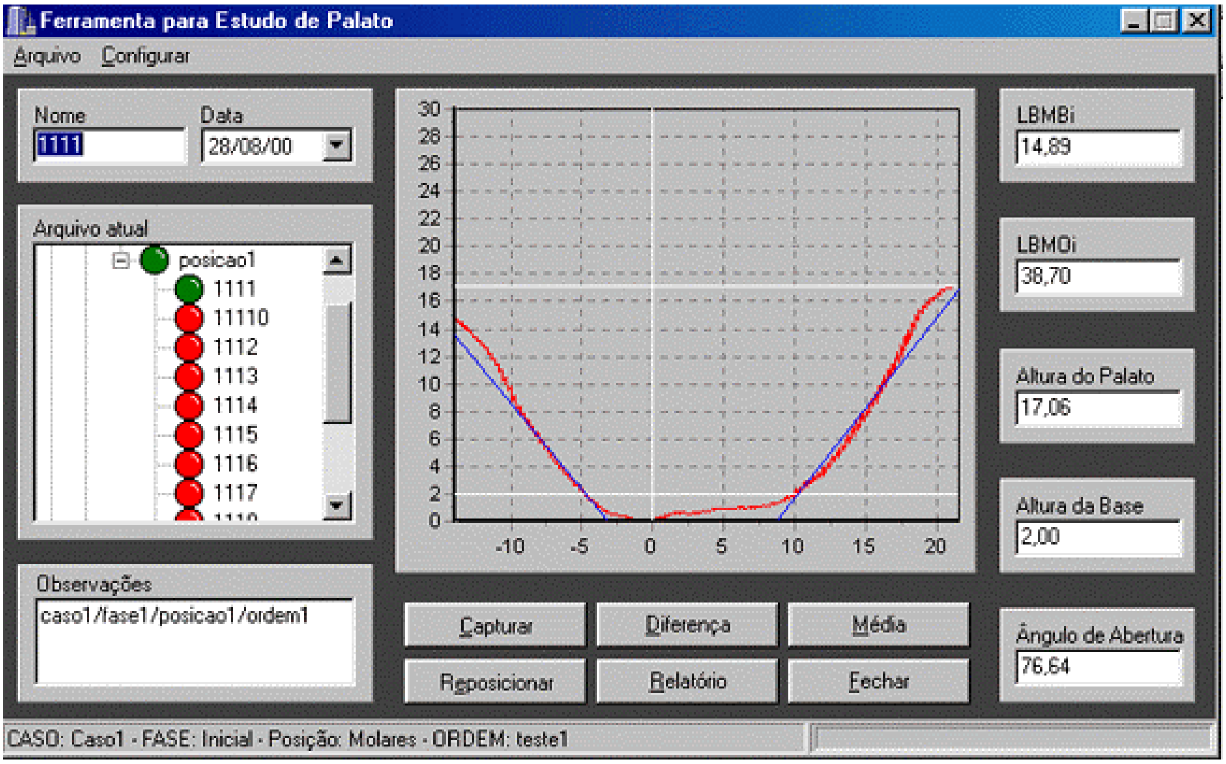


Figure 11. Program interface screen with a sample processed data.

5. Acknowledgements

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7. Notice

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