Analysis of dental holographic images for the command of automatic systems

Currently, the only method used in dentistry to reproduce a tooth or the maxillary with precision (200 to 500 µm) is the negative impression method with the help of more or less elastic materials, the patient's tooth being the positive. This method used for more than 300 years hasn't had any fundamental modification; the only technical progress was brought on the impression paste (Fig 1) (2).

En fact, the real problem, that is to say the physical cause of the measurement's imprecision, was never approached. In order to resolve (reduce) this question of imprecision we must decrease the energetic exchanges between the negative system, the positive system and the other environing systems, while decreasing the internal energy modifications of the negative system (Fig 2) (2).

This is the same as trying to keep the total's enthalpy considered like a fixed value, which isn't currently done in this method as the free energy is modified during the contact phase between the impression taking program with the other systems and the negative system's entropy is modified during the fixation of the mould (molecular modification).

So in order to not modify the enthalpy, we must use a system which has few exchanges with the environing systems and which doesn't suffer any structure modification).

The simpler a system is, the less sensitive it is to free energy variations and to entropy, this is why energetic quantum seem the most convenient.

We have chosen for negative system the laser wave and its interference in order to keep the tri dimensional aspect of our image.

Thus, to measure our object and carry out a shape study, we project a ray (laser) on the tooth. After having hit the target, it comes back by interference to a holographic plate with a reference wave. This last wave has the aim of reconstituting the virtual image during the revelation. It also enables the measurement of the distance travelled by the ray reflected by comparison of the light intensities (7).

Such a radiation must be constituted of rigorously parallel rays and the waves which constitute it must be in phase, also, the ray must be very fine to facilitate the sweeping of the goal. This is why we chose radiation from a gas laser with continuous emission.

The in mouth use, for a human being, and the risks between the radiation and the living tissues, specifically the gum, eyes and brain have led us to use a lower power laser (2W) emitting at 450nm (2 thesis) (1, 5, 9).

The reflected wave only hits the visible surface of the tooth so to apprehend the totality of the volume we propose to associate a second wave sweeping the object under an angle of more or less 180° compared to the first (Fig 3 et4).

The hologram will then have the total volume. An operator or an appropriate optical system will have to be laterally mobile to have the totality of the object. It will observe the effect of parallax which is characteristic of tri dimensional imagery. The dark fringes stop the reconstitution wave, that is to say the reference wave; the light fringes let them pass. There is diffraction and interference; the hologram appears as a wave fixed on the way (4, 7, 11).

At this level, 2 analysis modes can be used. The simplest consists of projecting on a screen the hologram, which will only have two dimensions here, in order to enable a detailed study of the tooth. This process is interesting as it enables the control at any time of the quality of the practioner's work. The second needs an analysis of our hologram with an analogue digital system with the help of a sweeping of the plate by an analysing tube (5).

The average holographic plate measures 9 cm by 12 cm and contains up to 10^{10} bits of memory (24.10^4 horizontal elements and 18.10^4 vertical ones), that is to say a $3000mm^{-1}$ resolution. A sweeping of 40000 lines can give a 510^{-3} mm resolution, that is to say a precision of about 5µ. The analysis of the elementary unit doesn't go over 1.10^{-5} seconds so a few minutes are enough to get a 5µ precision (the sweeping can be slow) (3, 12).

The quality of this analysis is a function of the level of lighting which must be adapted to the sensitivity of the detector, the used wavelength must also be adapted to the specific sensitivity while staying biologically acceptable and the parasites must be removed by the adjunction of filters (6).

These high precisions can be brought by analysis tubes which have 10* to 20ù layers and needles of 0.1 to 1µ (vidicon and plumbicon).

We transform without losing too much precision our tension analogue image but the application field of the system would be too low so we prefer working digitally. The interest of going digital is to stock data without any possibility of modification (Fig 5) (13).

This data should enable the command of a machine tool. It is about an automatic process enabling the command of a mobile mechanical organ to a position determined by an order. This position can be obtained by linear or angular movement depending on the freedom degree of the mobile (the order is delivered digitally, Cartesian or polar) (8).

A program band supports the translation in machine language. The numerical measurements of the hologram give these orders. They are transmitted to several cervo-order mechanisms which will distribute them to the guiding device (x, y, z) to position the head of the tool (Fig 6) (8).

If we do a reading of 1cm by 1cm (a tooth), we should have for coordinates 10^4 bits of information with a precision of 1µ. The lateral movement of the chariot is one of the constant factors, the 1µ data are perfectly realisable from a technical point of view. To this data we will add the data of the device such as (sporadically)

-number of tool
-drilling sequence
-brooch speed
-quick forward and back measurement
-spraying measurement
-end of program
-choice of metal factor for the manufactured piece.

The coordinates are translated and a relative rather than absolute manner ($M_1 \rightarrow M_2$ which is $\Delta x = x_2 - x_1$). It is useful at this level to notice that digital command device explores by gusts the data received from the program band (10000 to 50000 lines/second) to stock them and spread them correctly to the organs responsible for the final action (8) (2).

If we only want to reproduce the holographed object, it isn't necessary to modifiy the analysis program. We only need to sculpt a rough piece with the program previously established. The interest is of course debatable but whatever the analysis used, the technique will lead to a choice of different machines:

-electro erosion: for us, an impulsion generator and a very fine electrode (possible 10µ precision)

-electro chemistry: usable for correction and drilling

-electro forming: deposit on master piece. It can be a secondary application of our sculpture without modification of the program. The classic example is the electro galvanic depot technique.

-Chemical manufacturing: interesting for the realisation of removable devices with the mask technique

-ultra sound, high energy and laser for the finishing touches and the melding

-drilling which is the most logical process: either the tool or the instrument will be mobile (Fig 7).

These methods of working of the prosthetic piece can be used after modification of the analysis program in order to find a greater application field. Instead of describing the followed mathematical ways we will give an example: the realisation of a crown on the first left inferior molar (36) (10).

A crown has two characteristics, it is perfectly fitted to the tooth and the gum and adapts anatomically to the general aspect of the mouth (size).

If the first character can be considered as theoretical, the second needs an analysis of the tooth and also of the other teeth in order to resolve the occlusion problem (2).

2 cases can appear: the tooth to be crowned has a correct shape or it is very worn. In the first case, all you need to do is take two holograms, one before shaping the tooth and the other one after. The hologram before the shaping will enable the command of the external sculpture of the metal piece, the second hologram after correction by plus factor and the transformation of the negative into positive enabling the manufacture of the inside of the crown. The plus factor enables to preview the place of the cement.

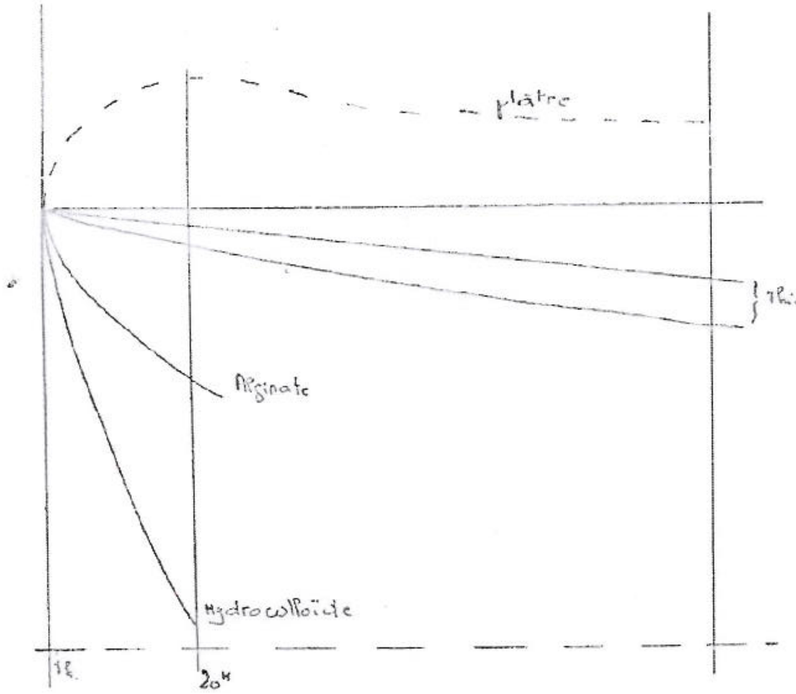
In the second case (worn tooth), the only way to realise an exterior shape is to use the memory of a code for a theoretical tooth corresponding to the tooth to be crowned.

The first action will be the analysis of teeth other than the 36th inside the mouth (and notably the 46th or the right inferior molar for symmetry reasons) in order to establish a wear coefficient and a general shape compared with the theoretical teeth we have memorized (Fig 5).

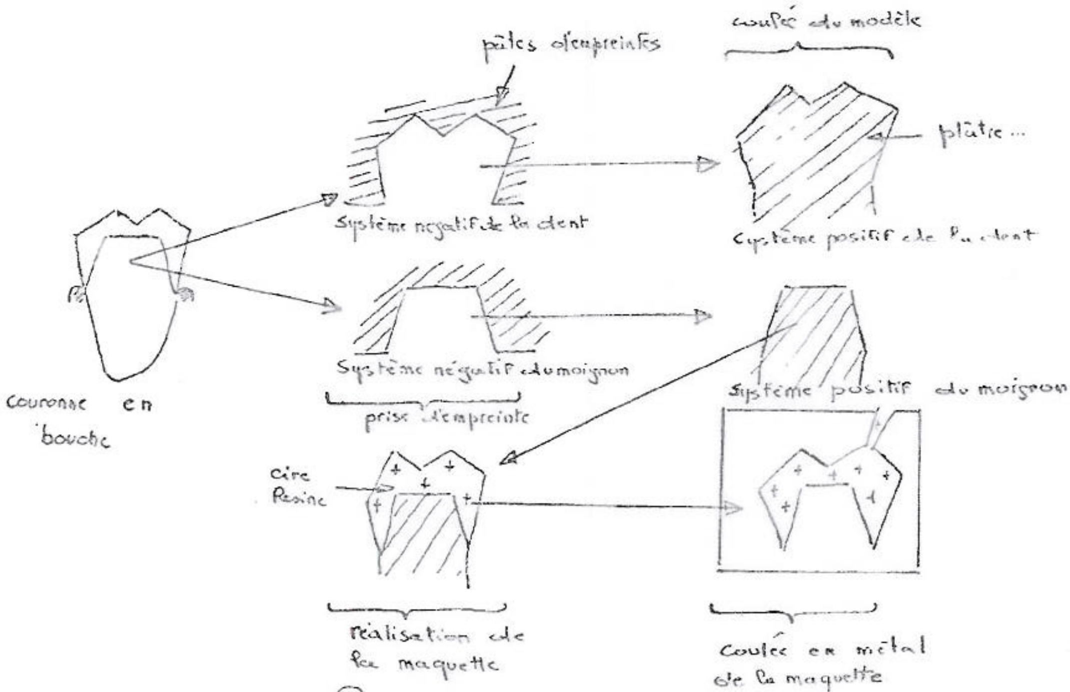
Before sculpting the exterior, we will take a second hologram when the tooth is prepared with the prosthesis then by comparing the chosen data (shape of the collet, height of the tip…) we will find a program of a theoretical tooth adapted to the values of the 36th. This program, before being modified to go through the command band of the machine tool will go trough the corrective report established with the other teeth. We will sculpt biologically with the patient's mouth. If the exterior shaping necessitates all of this complementary study, the interior shaping is identical to the first case (2).

Trials will be done to know is this wave doesn't bounce on the skin and can bounce on the bones: this will have the advantage of enabling the realisation of a non bloody method of implants (Fig 8) (2).

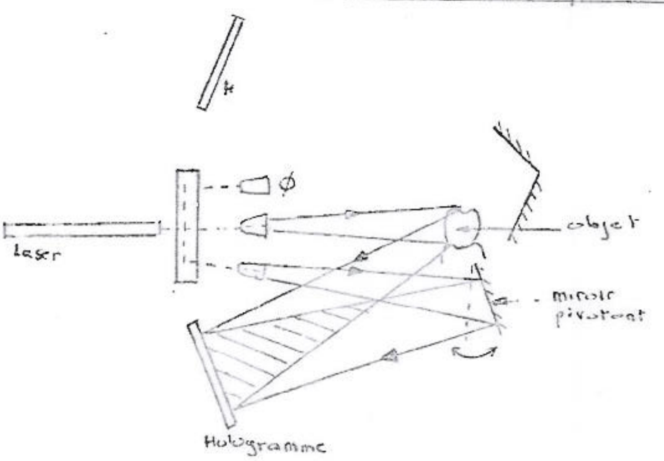
The envisaged system is perfectly doable. We use very fine measurement methods and very stable data supports which can only become finer and more stable. Possibilities and facilities for work are very important, so we have a great hope for the future of this metehod.



① Courbe comparative de variation dimensionnelle de 4 groupes de produits d'empreintes

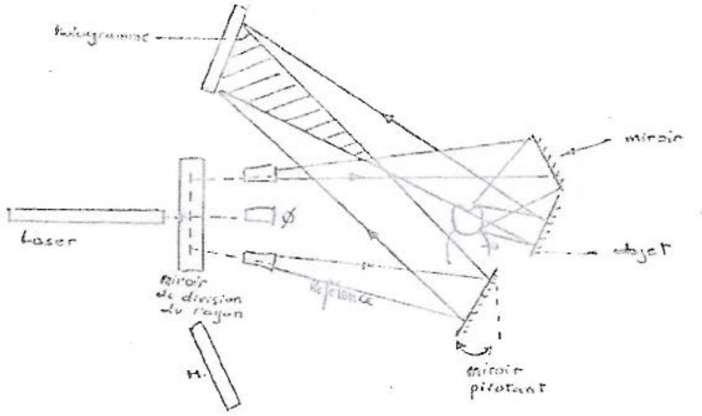


② Etapes classiques d'empreintes



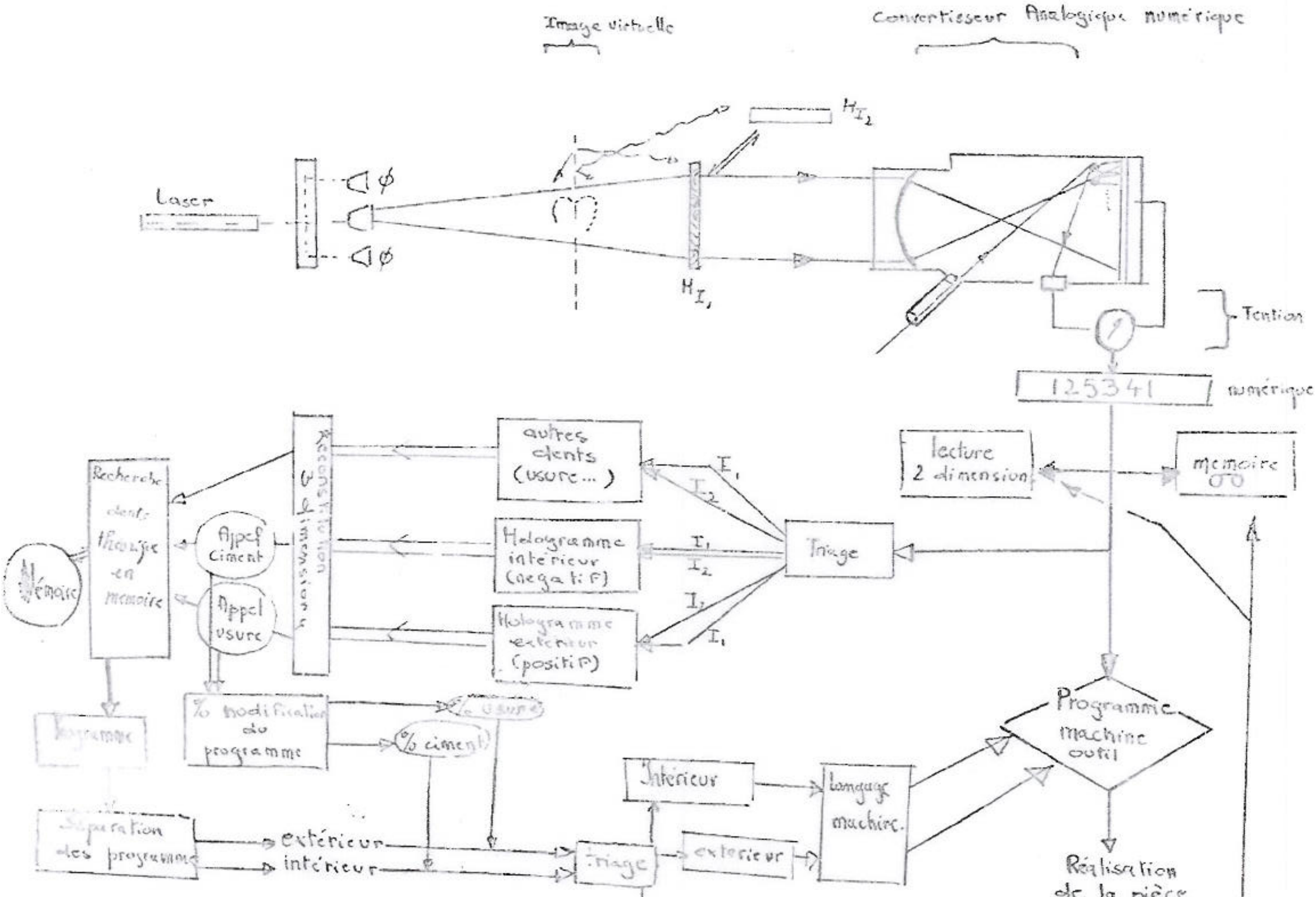
③ Prise de l'Hologramme I_1

face visible

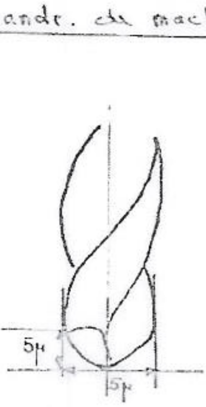


⑥ Prise de l'Hologramme I_2

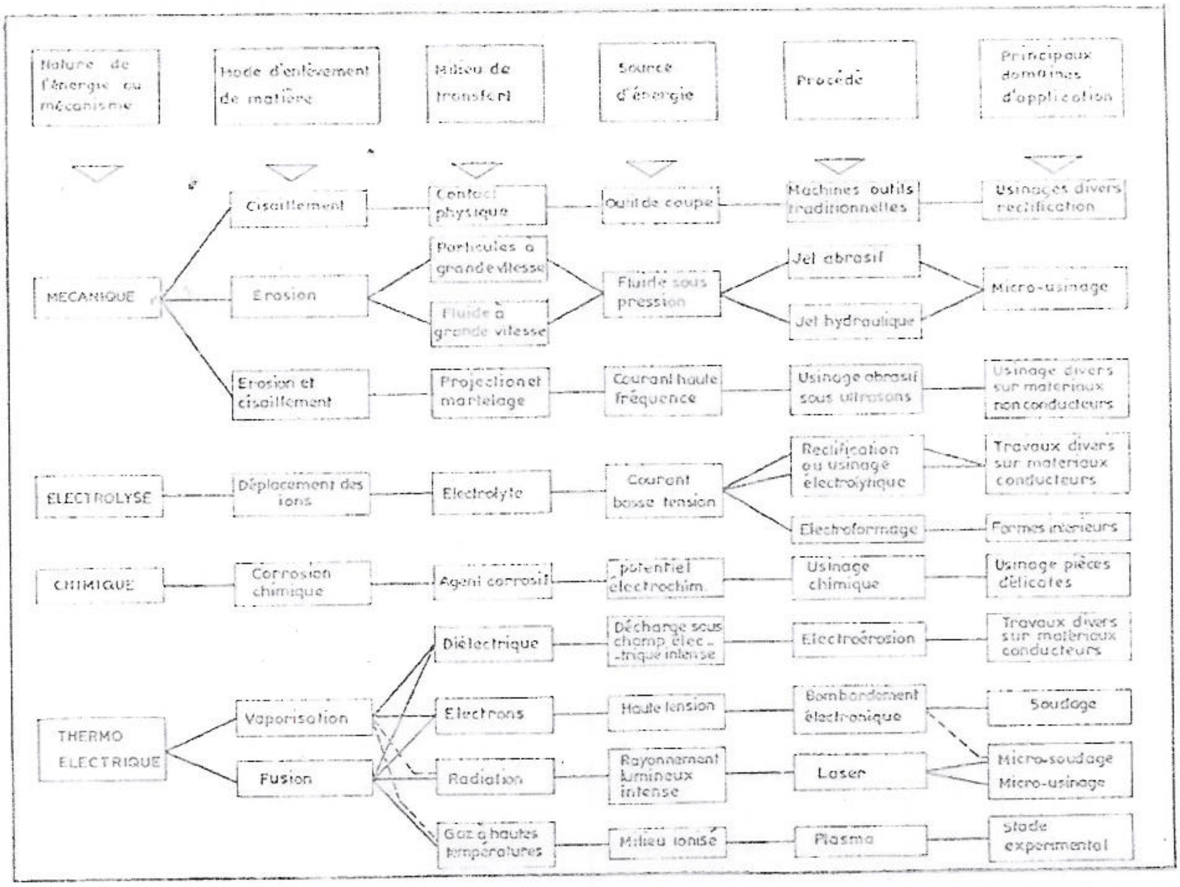
face invisible.



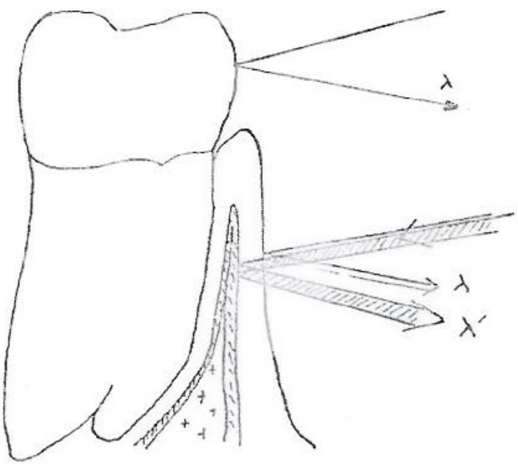
⑤ Programme de commande du machine outil



⑥ angle d'attaque de la fraise



(7) Différents usinages possibles



(8) Recherche du contour osseux avec λ'

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