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Development of High Speed and High Accuracy 3D Dental Intra Oral Scanner

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Abstract

3D digitization technology, commonly known as Intra oral scanning method is a modern approach than traditional impression methods in dentistry. Utilization of 3D digitization results in accurate mapping of oral cavity and eliminates number of procedures for making dental prosthesis. This paper unveils design of 3D dental oral scanner with software integration is proposed for high speed and accuracy. The main parts of the system are Intra-Oral Scanning (IOS) hardware, CPU and display monitor. The IOS hardware is designed using non-contact optical technologies based on the principle of confocal laser scanner microscopy results in high speed scanning. The light intensity is detected by photo-detection device, transforming the light signal into an electrical one which is recorded by a computer and can be reconstructed. The software is designed using merging of active triangulation method, surface reconstruction and Image processing tools, results in high accurate 3D image of oral cavity, which will be displayed on the monitor screen.

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Keywords: 3D digitization; prosthesis; Intra-Oral Scanning; Confocal laser scanner microscopy; Surface reconstruction

1. Introduction

Three-dimensional scanning of an oral cavity in Orthodontics and restorative dentistry is required for an accurate mapping which sequels in the elimination of long procedures. The main goal of using this 3D digitization

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technology is to minimize the diagnosis time and pain of the patients and maximize the accuracy for making prosthesis using CAD/CAM systems. The present scenario of traditional impression method has long work flow process starting from dentist's office to the procedures leading to execute prosthesis. The traditional workflow process is illustrated in Fig.1. The final output of build prosthesis using this method has accuracy limitations which results in uneasiness of patient even after implanting. The proposed workflow process for making prosthesis/abutments is illustrated in Fig.2. 3D digital Intra Oral Scanner is developed which scans the oral cavity of the patient in less time and with high accurate results. This proposed workflow process simplifies traditional workflow process by eliminating long procedures.

In past, many researches have been conducted in the dental field for making prosthesis through 3D digitization. In 1973, Dr. Francois Duret was the first one to propose the CAD/CAM technique to the dental world. Later along with Dr. Christian Termoz, they patented the method of and apparatus for making prosthesis, especially a dental prosthesis as in [1]. Later in 1980s, Dr. Werner Mőrmann and Marco Brandestini introduced the first digital oral scanner with CAD/CAM system for restorative dentistry. The product was commercially available in 1987, named as CEREC® by Sirona Dental systems LLC (Charlotte, NC) as mentioned in [2]. The product was patented later on as Method and apparatus for the three dimensional registration and display of prepared teeth as in [3]. According to present scenario, more than ten Intra-oral scanning devices are developed throughout the world. But due to accuracy limitations and scanning speed issues only a few product are commercially available in the market. In the year 2009, Sirona Dental systems launched CEREC AC® powered by BlueCam®, culminating the technical improvements. The design of Intra-Oral Scanner hardware was based on the Confocal microscopy principle [3,4] and on the active triangulation technique [5]. The main disadvantage of using this technique was that it needs coating on the teeth's before scanning. Even the proprietary format of output files, speed and accuracy were still not determined. Similarly D4D Technologies LLC introduced E4D dentist system in year 2008. The hardware consists of confocal sensors which assist in altering the pivot position of the laser beam. The design of software system has a special feature Autogenesis, for auto detecting the scan object and marks the finishing line on the display model on monitor screen. Main advantage over CEREC AC® using E4D is in most of the cases teeth coating is not required. But the disadvantage was that the Intra-oral scanner hardware must be held at a specific distance from the object, which results in low accuracy and speed. New technology based on the two channel pulse time of flight laser scanner is also developed and discussed in [7], but so far no commercial machine related to this technology is in the market. Denmark company named 3 shapes, commercialized their product TRIOS® for dental restorations. 3D geometry of the surface of an object was displayed on the monitor screen using confocal pattern projection with fast scanning time as in [8]. The software also has similar features like E4D but in this case though the focal plane is shifting, the object being scanned will be tele-centric and its magnification scale is also maintained. This is advantageous for dentist as well as the patient. Colour display with adjustment features for making prosthesis is also featured along with the software but accuracy is not yet defined. A comparative analysis of Intra-oral 3D digital scanners for restorative dentistry was done by S Logozzo et al. (2011) as described in [9]. It concludes not to state which of the device is the best one amongst all reviewed, based on high speed and accuracy. The evaluation was based on the working principles, features and its output in terms of performance. In this paper, we propose a design for 3d dental

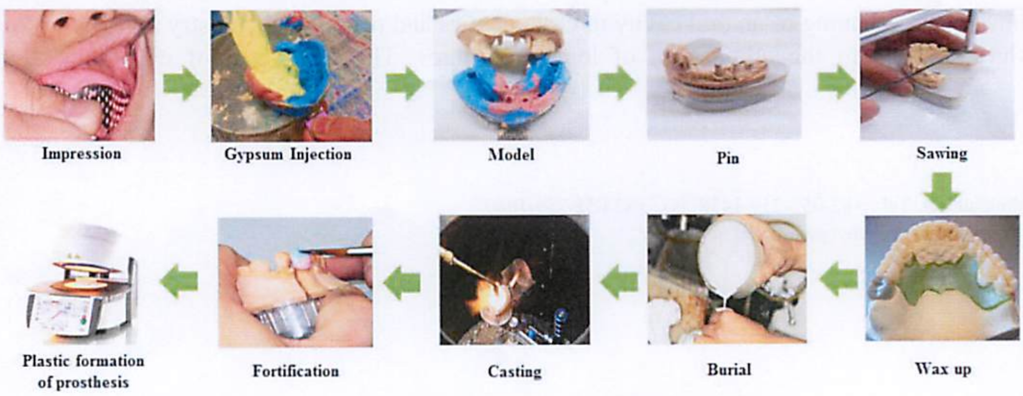

Fig. 1. Traditional workflow process for dental impressions.

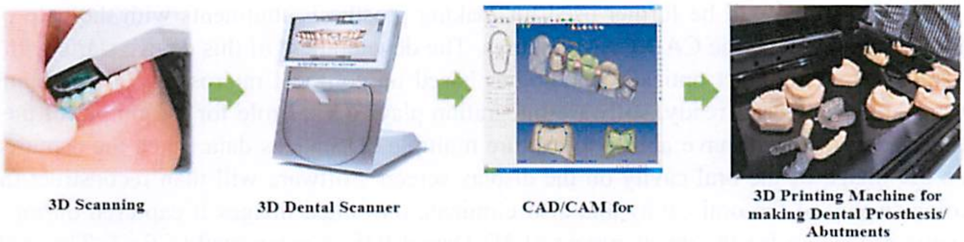

Fig. 2. Proposed workflow process for dental impressions.

IOS hardware for high accuracy and high speed. For this, purpose three light sources are introduced in the hardware which is capable to capture about 1000 points per second when subjected to scanning object. The active triangulation method is used for scanning the object along with the merging of surface construction and image processing software. The image processing using point cloud was taken into reference as mentioned in [14]. The displayed image can be transformed into CAD/CAM for the exact geometry mapping of the oral cavity which is further used for making prosthesis/abutments.

Nomenclature

IOS	intra-oral scanner
CLSM	Confocal Laser Scanning Microscopy
A	calculated amplitude or correlation measure
f	periodic function
I	Index of each sampling
p	angular position
ϕ	constant offset for light sensitive element j

2. Systematic procedure to develop 3D Intra-oral dental scanner

The final goal of this research is to develop a highly accurate and high speed 3D dental oral scanner capable of capturing multiple 2D images of the oral cavity of teeth's and display 3D image on the monitor screen. The 3D

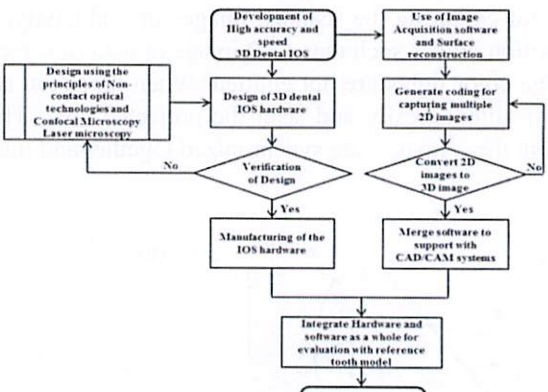

Fig.3. Schematic procedure to develop 3D dental IOS for high accuracy and speed.

image of oral cavity so formed will be further used for making prosthesis/abutments with the help of 3D printing machine or milling machine using the CAD/CAM features. The development of this device starts with the design of IOS hardware using the non-contact optical technologies based on confocal microscopy laser scanning principle. Once the hardware of the device is ready, software integration plays a vital role for the output of the scanned oral cavity. The software designed will have ability to capture multiple 2D images data. Then the captured images will be modified into 3D image of the oral cavity on the display screen. Software will than reconstruct the image with accuracy and color display of the oral cavity and also eliminate unwanted images if captured during the scanning. The brief schematic procedure for the development of 3D Dental IOS is mentioned in fig.3. The evaluation of 3D dental IOS device will be carried out on the reference tooth jaw model for measuring the accuracy and speed.

3. Development of 3D dental IOS

3.1. Design of 3D dental IOS hardware

Confocal laser scanning microscopy principle (CLSM) will be used for designing the 3D dental IOS hardware. The main reason for using CLSM technique is that it locates the focused image from the depth with the help of optical sectioning process. Laser as a light source is used for scanning the 3D digitization of the oral cavity of teeth's to achieve the accuracy. Combination of laser as a light source and CLSM technique helps to capture large amount of images and transfers into computer. The image acquisition rate for scanning the oral cavity is approximately 1,000 data-points per second which helps in high speed scanning. CLSM acquired images can be used for surface reconstruction with the help of software and obtain interior imaging of non-opaque specimen. A laser beam is projected through an aperture as in fig.4(a) and then is focused by objective lens into small focal volume within or on the surface of specimen. The image is detected by the photo detection device which than converts the light signal into an electrical one which is recorded by the computer. Here the CLSM principle will be used with the combination of optical system for confocal microscopy patented by Dr. Markus Berner as in fig.4(b). The laser light source will act as an illuminating pattern producing light oscillation on the object, this oscillation may be spatial and/or may be time varying as in [11]. Time varying pattern will be applied; hence the large number of 2D images will be captured by a single scan. It corresponds to focus plane, which is placed in different positions with respective to illumination pattern.

The line diagram of the main components used based on the principle of CLSM is shown in fig.5(a). There are three main laser sources of different colors (red, green and blue). Four dichroic coated plates, image sensor, camera, beam splitter, etc. are used for capturing the scanned images of oral cavity. Now, when the red color laser source emits the light, focusing position moves such that a 3D image of pattern is recorded below the coated plate 3, at that time the green color and blue color lights are not emitted. When the green color light source is on, other two light sources will be switched off automatically and scan the projected area. The pattern so formed will be recorded below the coated plate 4. Both these images are synchronized together and image will be formed with the help of

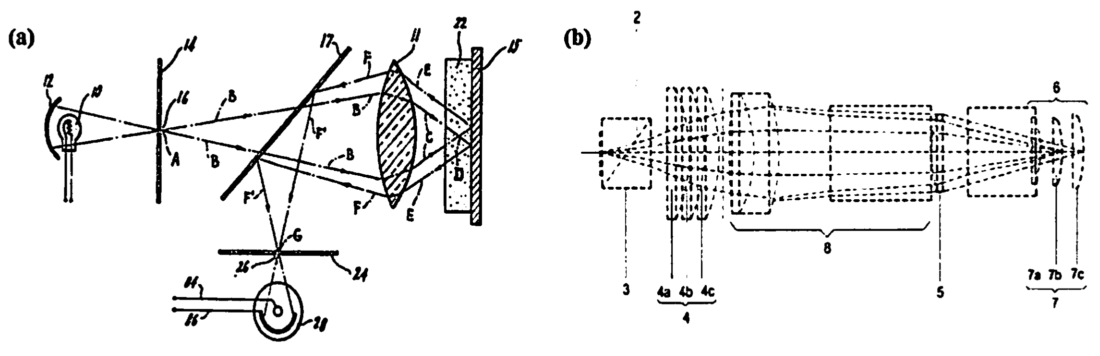

Fig.4 (a) Confocal microscopy principle [10]; (b) Optics for confocal microscope [11] coated plate 1 and coated plate 2. Now coating plate 2 transmits the light from red and green laser source and reflects the light from blue laser source. Measurement of color display is executed by the amplitude of time-varying pattern projected onto the scanning object. It is found out for each sensor element. The light sources are turned off one by one as mentioned above. Once the amplitude of each light source is determined the focus position is shifted to next position and the whole process is repeated. Amplitude is calculated by using the below mentioned equation:

$$A = \sum f(p_i) I_i \tag{1}$$

Preferably the periodic function averages to zero over a pattern oscillation period, i.e.

$$\sum_i f(p_i) = 0 \tag{2}$$

To generalize the principle of plurality, the angular position of the illumination pattern for a specific light sensitive element may consist of an angular position associated with the illuminating pattern plus a constant offset associated with the light sensitive element as in [8]. Thereby the amplitude of the light oscillation can be calculated as:

$$A_j = \sum f(\Phi_j + p_i) I_{i,j} \tag{3}$$

By this way the amplitude can be found out and with the integration of software along with the developed hardware, 3D image of oral cavity is displayed with high accuracy and high speed. The 3D presentation of developed IOS hardware is shown in fig.5(b).

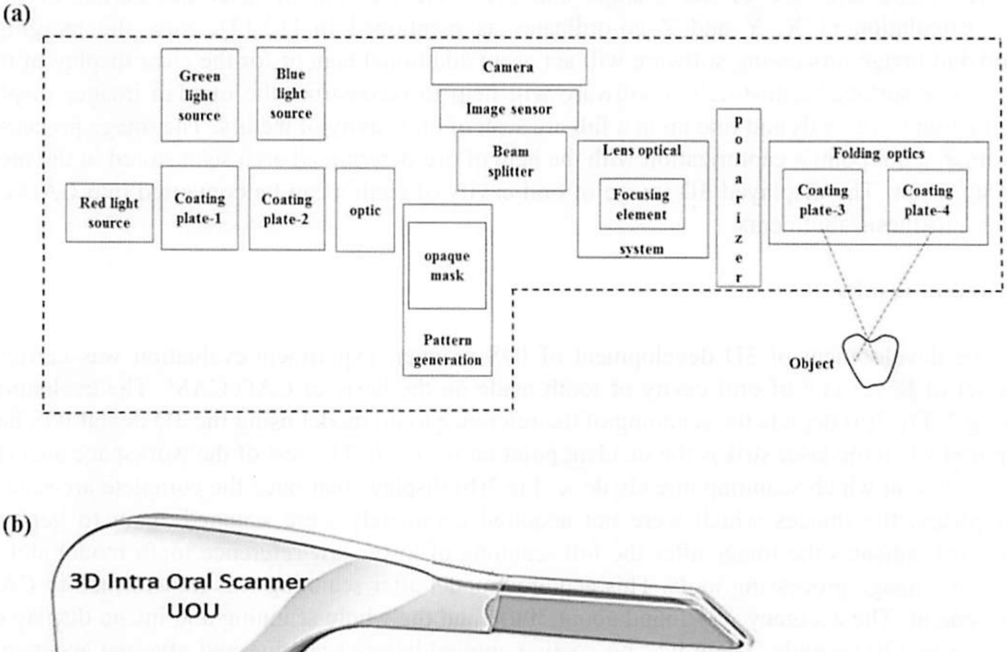

Fig.5 (a) Line diagram of main components in IOS hardware using CLSM principle; (b) 3D view of 3D IOS hardware.

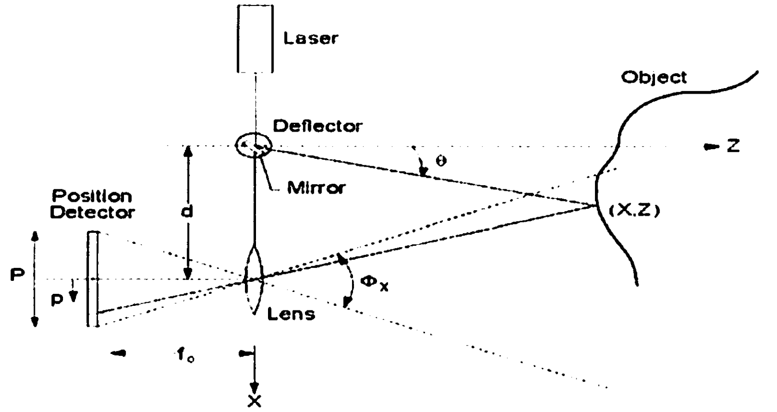

Fig.6 2D active triangulation method [12].

3.2. Development of Software

Software is made with the help of active triangulation method and merging of surface reconstruction and image processing software as a whole. Based on the concept of active triangulation as proposed in [12], a laser beam is deflected by a mirror and scanned on the target object. As discussed before in hardware, the location of image is captured by the photo-detector and measures the location of the image of the illuminated point on the object. Approximately 1000 dot size points will be projected on the scanning object strikes back and capture the images. This technique is called as active triangulation because the laser dot, camera and the emitter forms a triangle. The angle ϕ can be determined looking at the location of laser dot in the camera field as shown in the fig.6. These three data determines shape and size of the triangle and gives the location of laser dot corner of a triangle, by trigonometric calculation in X, Y and Z co-ordinates as mentioned in [12,13]. Now the merging of surface reconstruction and image processing software will act as an additional benefit for the clear display of the 3D image of oral cavity. The surface reconstruction software will help to reconstruct the overlap images displayed by the hardware in fraction of seconds and line up in a full arc scan of oral cavity of teeth's. The image processing software will help for missed out point's capturization with the help of pre-determined arch scan stored in the memory giving the best display result. The displayed 3D image of oral cavity of teeth's can be converted into CAD/CAM file for making further prosthesis/abutments.

4. Experiment and results

Based on the development of 3D development of IOS scanner, experiment/evaluation was carried out on the reference model of lower jaw of oral cavity of tooth made on the basis of CAD/CAM. The evaluation process is described in fig.7. Fig.7(a) depicts the scanning of the reference tooth model using the 3D dental IOS hardware. The image is acquired when the laser strikes the incident point on the teeth. The rest of the workspace area shows the 3D image of the teeth's on which scanning already done. Fig.7(b) displays that once the complete arc scan of the lower jaw was completed, the images which were not acquired completely were scanned again to get the maximum accuracy. Fig.7(c) indicates the image after the full scanning of lower jaw reference tooth model and with surface reconstruction and image processing tools. This acquired model after scanning was transformed to CAD/CAM file for the measurement. The accuracy was found about 30µm and the whole scanning and image display of lower jaw teeth's was done in 120 seconds. There was no coating applied before scanning and give the accurate results. But there are possibilities when sometime coating is required. With the help of these scanning references acquired further it can be used for making prosthesis in 3D printing machine and abutments with 3D milling machine.

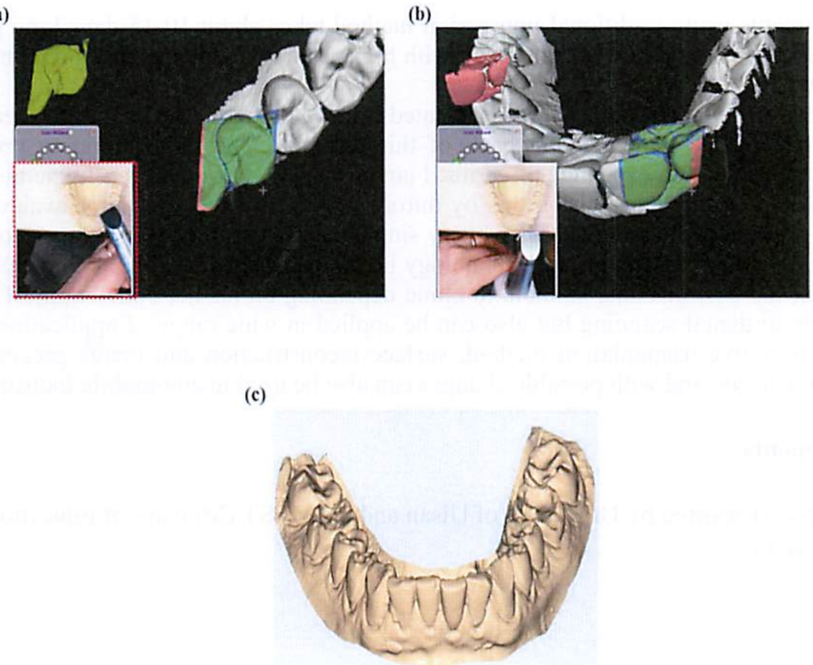

Fig.7 (a) scanning of reference lower jaw tooth model; (b) scanning the missed out area of oral cavity; (c) 3D display of scanned reference tooth model.

Furthermore, the results obtained by our developed 3D dental IOS were compared with the existing commercial products as shown in Table.1. Accuracy and speed of CEREC®AC Blue-Cam by Sirona dental system and Trios by 3Shape are yet not defined as mentioned in [6] and also 3D Progress by MHT S.P.A-MHT optic research, the scanning speed is 180 seconds and accuracy is not defined. All the compared commercial products may/may not need coating before scanning to get the 3D display of dental cavity.

Conclusion

In this paper, we proposed the design and development of 3D dental IOS for high accuracy and high speed. The results obtained after scanning the oral cavity using 3D dental IOS can be interpreted in CAD/CAM software. These results are further used for making dental prosthesis/abutments using 3D printing machine or milling machine in less than a day. By using this technology, the accuracy achieved is up to 30μm and the scanning time is nearly 120

Table 1. Comparison result table of commercial products and developed scanner.

Intra Oral Scanner	Company	Accuracy (μm)	Scanning Speed (Sec)	Disadvantage
CEREC®AC- Blue cam	Sirona Dental System	-	-	Needs coating
Trios	3Shape	-	-	Output file not disclosed
3D progress	MHT S.P.A-MHT Optic Research	-	180	Needs coatings occasionally
Developed Scanner	Developed Scanner	30	120	Coatings needed rarely

seconds which is the great benefit over the traditional impression method in terms of accuracy and speed. Making prosthesis/abutments using traditional impression method takes about 10-15 days long procedure. On the contrary, this proposed technology takes less than 1 day with high accuracy which is far more convenient to both, the dentists and the patients.

As a future work, this research will be dedicated in developing the technique further more to enhance accuracy and speed. There is one hygienic drawback of this research. The same scanning probe is introduced to every patient's denture results into exchange of germs. I am presently working on this hygienic quotient. As a future work, I am keen to complete my research on this by introducing the hygienic or autoclavable tip over the scanning lens which can be disposed or autoclaved after every single use. No scanning techniques so far developed or proposed can be considered unparalleled, as each technology has some drawbacks. This completely depends on the dentist to choose amongst the best machine suitable to clinic depending on his/her convictions. The technology developed is not limited only to dental scanning but also can be applied in wide range of applications. The software integration with the help of active triangulation method, surface reconstruction and image processing tools can be used for scanning of human ears and with possible changes can also be used in automobile industry as well.

Acknowledgements

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