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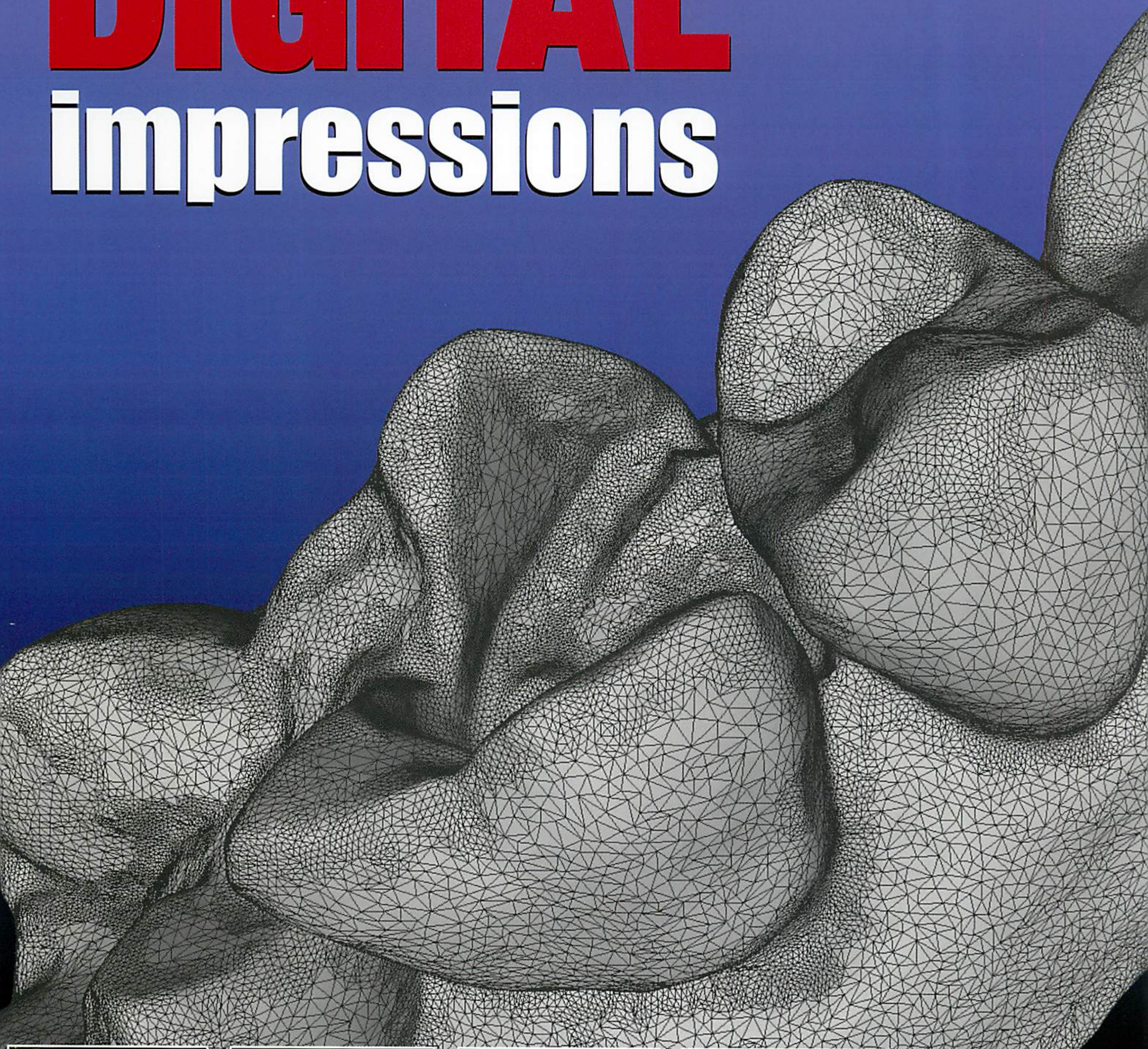

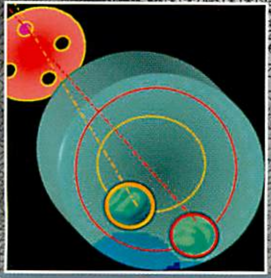

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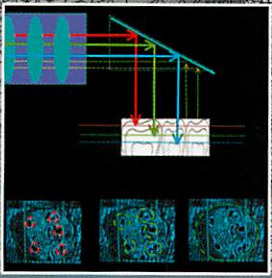

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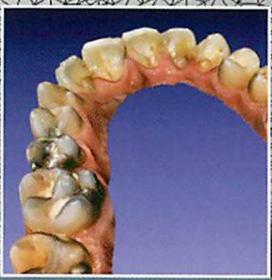

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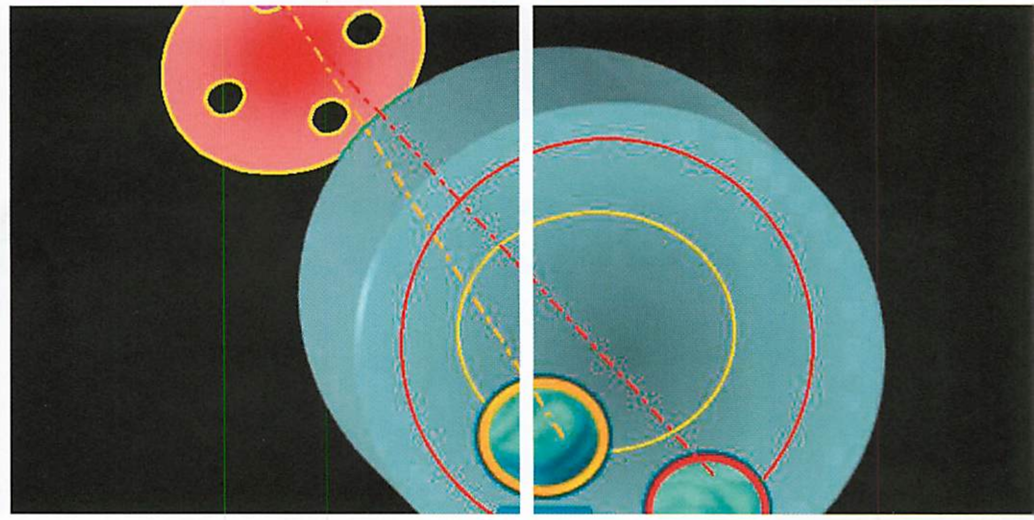
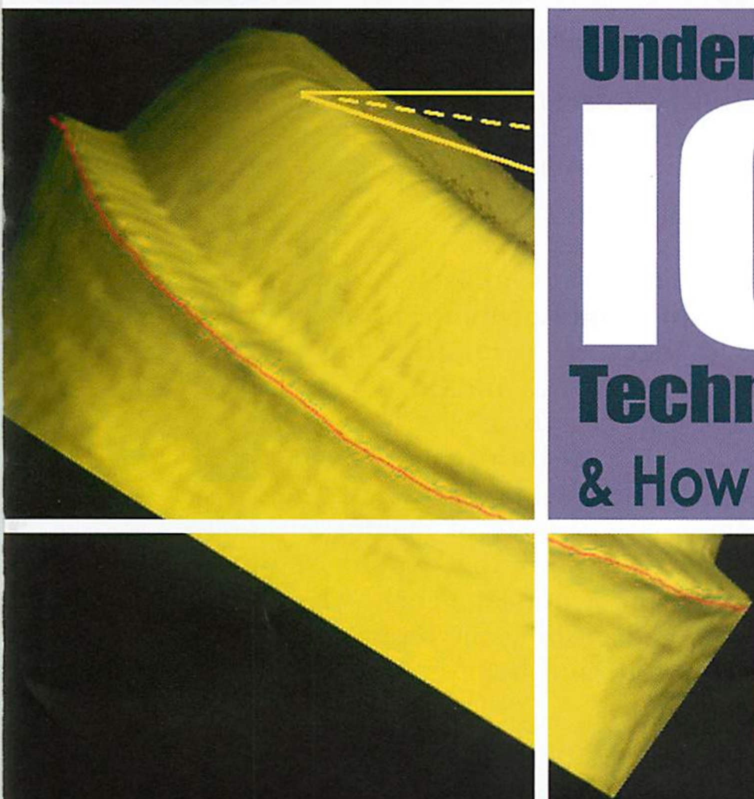
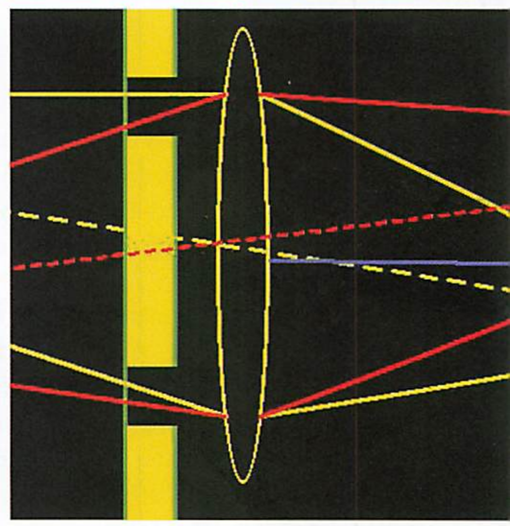




Understanding IOS Technologies & How they work



By
Dr François Duret
& Bruno Pelissier

17

Understanding intraoral scanner technologies

Since I started working on my thesis on optical impressions back in the '70s, our society has been completely transformed by technology.
The dental industry is no exception.

These changes are significant. Many dental laboratories are now used to speaking about, and working with, CAD/CAM technology. On the dentist side, traditional impression materials, that have been used for the past 300 or 400 years, are finally being replaced by optical impressions via intraoral scanners. These changes are both difficult and exciting. Difficult because we are changing the ways in which we have always worked. Many of those with whom we work - both dentists and technicians - refuse to embrace these technical advancements, preferring the old tried and tested methods. With retirement just around the corner, they are putting off change until the end of their career.
Yet these changes are also exciting. This professional upheaval is leading to new opportunities and possibilities.
These changes are revolutionising the way in which we work, and in a major way, because impressions are the basis for almost all collaboration between laboratories and dental surgeries.
Computers are capable of making infinitely complex calculations that would be nearly impossible for a human being. We are still exploring and pushing the limits of what we are capable of: and believe me, this change is for the better.

How is a digital impression possible?

An alginate surface is seen by the human eye as a solid piece of matter. In reality, it must be understood to be a series of 'points' that give the impression of uniformity and solidity due to their proximity to each other. Of course, on an atomic level, there are actually spaces between each of these points.

When taking an impression, we are reproducing the patient's mouth to make it accessible so that work can be continued with the patient in absentia. Any technique that allows for the copying and 3D reproduction of the dental arches can be considered to be 'impression taking'.
This copy can be a simple surface transfer, without any additional information on the copied object (classic impression techniques).
Alternatively, the transfer technique could involve digitally recording the spatial position of each surface point in x, y and z. This type of technique corresponds to IOS system techniques. IOS transfer techniques are becoming increasingly popular, as digital impressions can be imported direct to CAD software for restoration design.

“For the computer, an optical impression is a file made up of a series of points...”

A cloud of points

During the intraoral scan, the handpiece records a series of points that are very close together. The position of each point is recorded with at least three values (for x, y, and z). These three figures correspond to the spatial position of the point in relation to a central reference point (with the values 0, 0 and 0). This is referred to as a ‘cloud of points’.

For the computer, an optical impression is a file made up of a series of points. The greater the number of points the larger the file; the greater the precision the greater the number of points needed, as the distance between the points will be smaller.

For a precise capture of a dental arch at 10 microns, the computer will record millions of points. If the optical impression requires 3000 views per second, as is the case with IOS systems, we are talking about hundreds of millions of points to accurately reproduce a dental arch.

This explains why intraoral scanners have only become a viable option in the past few years. A computer that could manage that many calculations was, until recently, very expensive - too expensive for our line of work.

Measuring with accuracy

The problem scientists were confronted with for years was how to measure the exact position of these points in the mouth in order to reproduce a dental arch.

In dentistry there have been various techniques for doing this. One of these was the micro-palping technique (used roughly between 1995 and 2010). Micro-palping impressions were relatively slow.

For this reason these techniques are not really suitable for intraoral impressions, despite several trials (Mushabac or Rekow). The slightest movement when taking the impression led to reference errors.

In contrast, optical impression techniques are much faster and the handling is relatively simple. This explains why the majority of IOS systems on the market use optical impression techniques to capture the points in the mouth.

Although we have been talking about optical impressions for years, in reality these systems took a long time to develop correctly for dentistry.
This is not because the techniques were inaccurate, but the ideas came too early for the hardware to handle. Technological developments (such as computer calculating power, CCD precision, graphics cards, smaller lenses and LED lighting) have made these techniques faster, more precise and cost effective.

IOS technologies have gone through various phases of development. Each new phase often evolves from those that came before, though this is not always the case. In order to properly understand what is going on inside a scanner today, it is useful to understand how the underlying technologies evolved.

Evolutions in IOS techniques

In this article we shall discuss various optical impression techniques, starting with the earlier ones and moving on to more recent technologies, in the following order:

1. Triangulation (and the evolution to structured light)
2. Confocal
3. Active Wavefront Sampling & in focus / out of focus
4. Dynamic Stereoscopy

1 Early approaches to optical impressions, triangulation and structured light in dentistry

Binocular vision (stereoscopy) and triangulation

This technique is the basis for almost all IOS technologies. Traditionally, it has also been one of the most used in dentistry. Human binocular vision is reproduced, allowing for the position of an object to be calculated because we know the position of the two points of view. As fig. 1 shows, the same point in a dental arch, such as a cuspal point, will not have the same position on the retina of the right eye (x & y) and on the left (x' & y'). The brain is instinctively capable of finding these two points (which we call homologous points), observing the different positions on both the retinae and deducing the distance which separates the eyes from this point. IOS systems working on this principle use the same technique: by observing the points in a dental arch, an IOS system can construct a 3D view. Mathematically, calculating this distance (z) is a simple trigonomic calculation that any computer can carry out quickly.

Projecting and sweeping a single beam of light

This phase, which is too slow for impression taking in the mouth (due to patient movement as the light beam moved), was used with bench top scanners in the mid 2000s, as there was no risk of the plaster model moving. It is still used in the study of mandibular movements today.

Since the oral cavity is dark and it is

fig 1 Stereostopic view at the level of the human eye

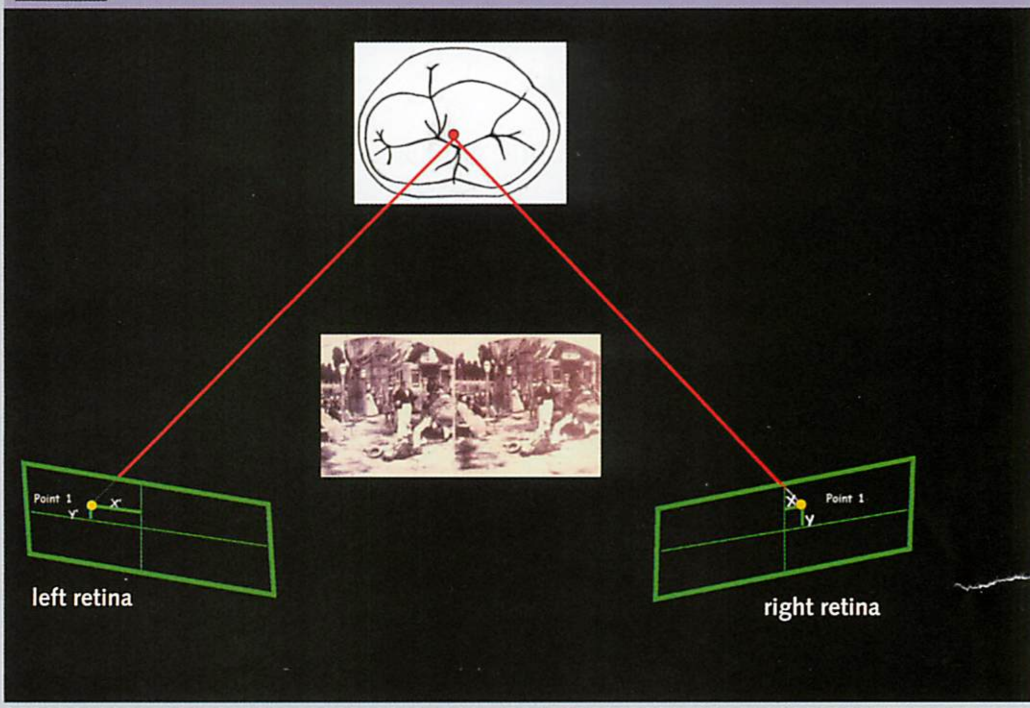
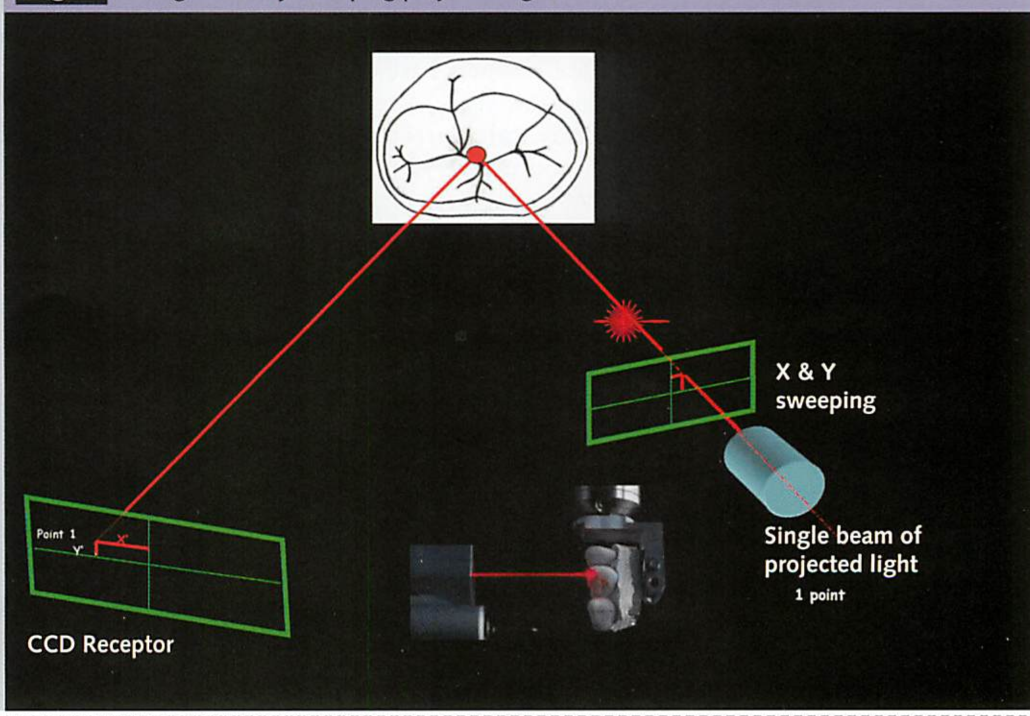
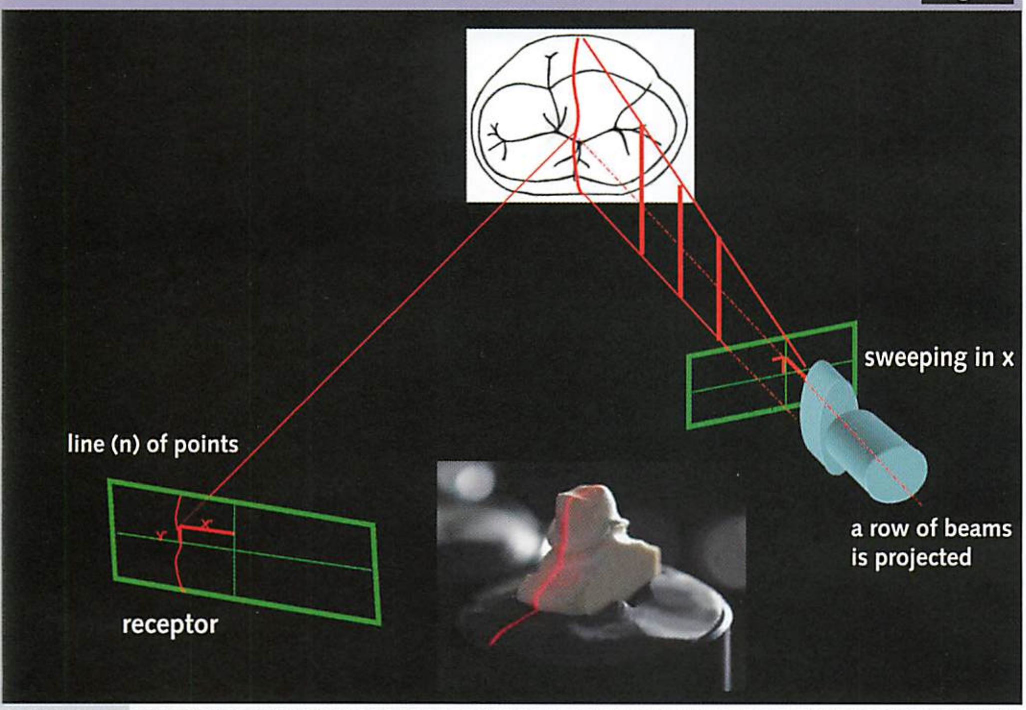


fig 2 Triangulation by sweeping projected light

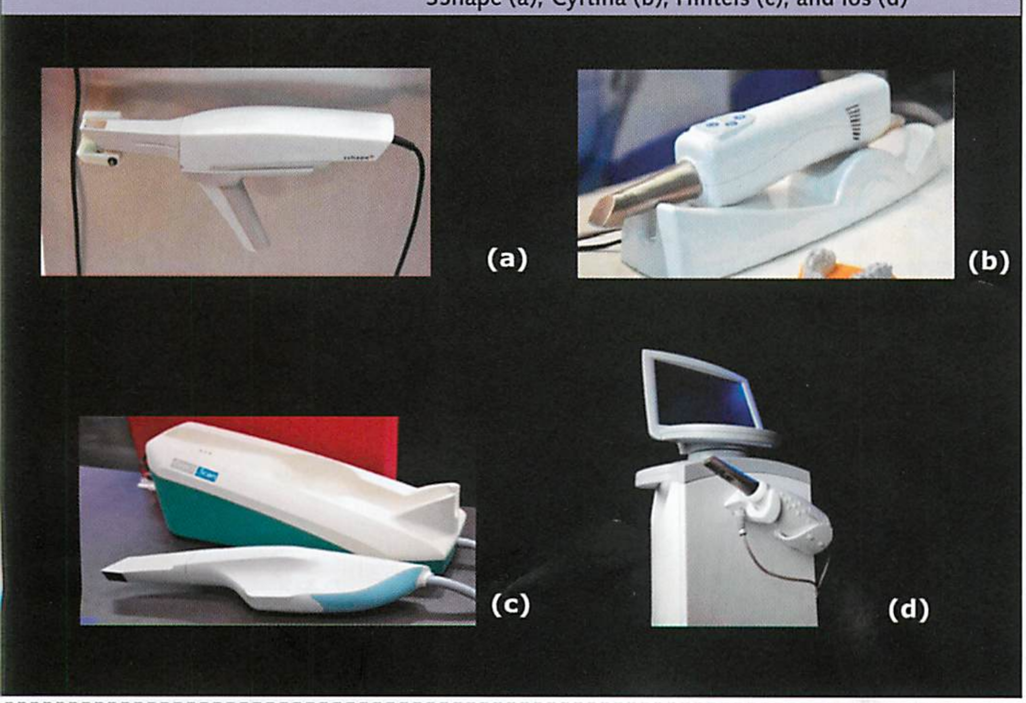


“Structured light remains a popular IOS capture technique...”

Triangulation: sweeping a line of beams (or points) **fig 3**



First generation structured light scanners (these are no longer available today): 3Shape (a), Cyrtina (b), Hintels (c), and Ios (d) **fig 4**



difficult to find homologous points (especially on smooth, white, shiny surfaces) the second eye was replaced by a projected beam of light. In fig. 2 we can see both distances (x & y) and (x' & y') seen on the retinae. The x and y distances are pre-programmed into the computer, and are the position from which the sweeping beam of light is projected. The computer measures position of the light beam on the CCD (x' and y'), which allows it to calculate the third dimension (z), which is the distance of the CCD from point on the object. This is a straightforward trigonomic calculation.

Sweeping with a line (or row) of beams

The next development was the projection of a row of beams on to the tooth (fig. 3). When used with an ultra-fast motorised sweeping system (piezomotor), over 3000 images could be captured per second.

These were the early days of structured light scanning, and this technique was used by many first generation IOS systems (fig. 4). In general these scanners project a row of red or blue light beams which continually sweep over the dental arch. The data is captured by recording the pattern that the projected light makes on the CCD, by taking a series of photos in quick succession.

This made handling the in the mouth easier than for a single beam. The operator simply moves the handpiece over the surface of the dental arch in order to capture the optical impression, but care had to be taken.

The correlation of the views (the overlaying of the photos one after another in order to reconstitute a single object) is ensured in two ways. Firstly, as much of the intraoral situation as possible has to be captured before moving the handpiece; This is ensured by a quick succession of photos.

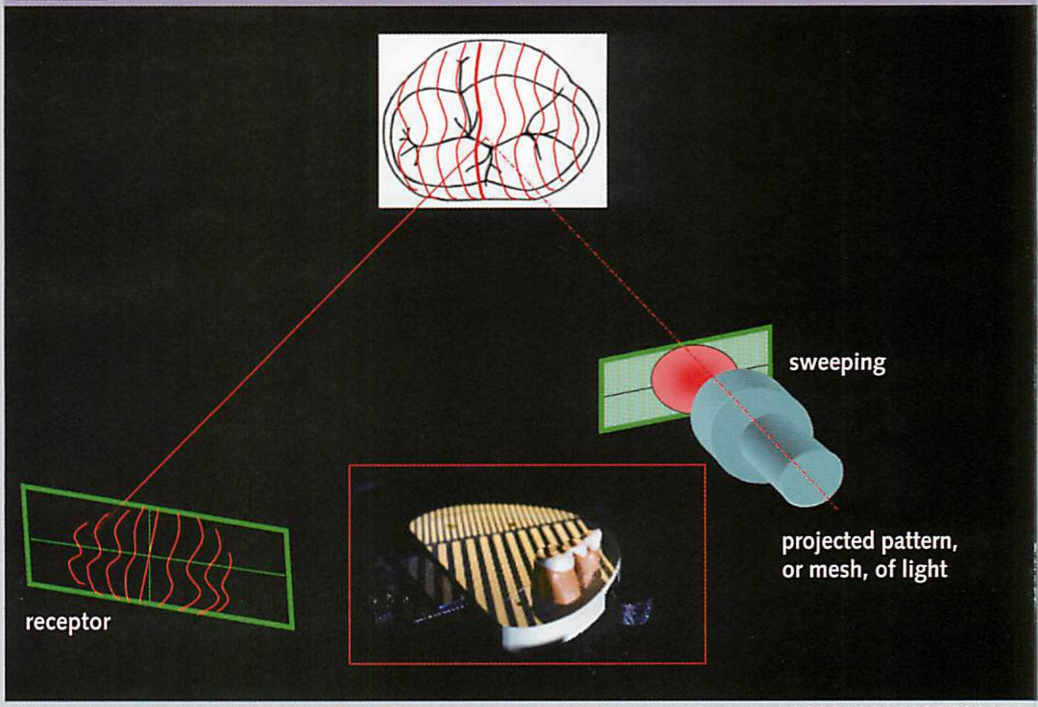
Secondly, a constant overlap has to be maintained (usually 1/3 between two views) - this is possible if the operator does not move the scanner too quickly. This technique is highly dependent on operator skill.

"There are numerous variations of the structured light technique..."

Sweeping with a mesh of lines (or pattern)

Sweeping with a mesh of parallel lines (that form a pattern) is a further development in structured light scanning (fig. 5). The principle remain the same, but the projection of a pattern can make the process faster and improve the precision.
Each IOS system is unique, and there are numerous variations to the sructured light technique. Certain systems projeced a pattern (or mesh) of light, whilst others project various patterns (or meshes) of light from different angles at the same time (research done by G Hausler).

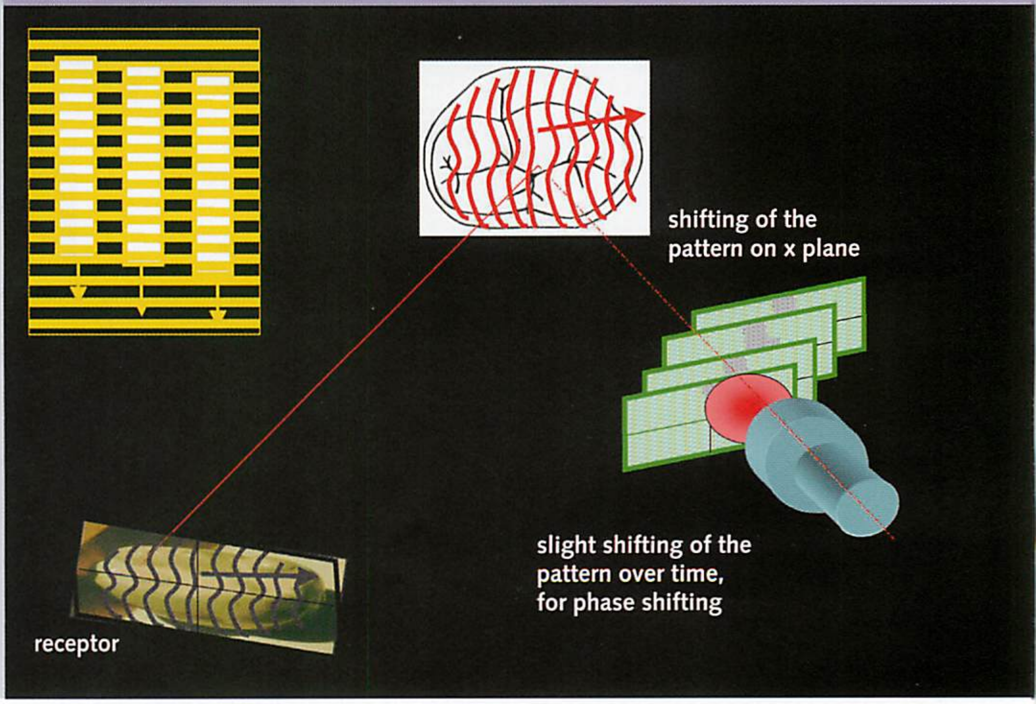
fig 5 Triangulation with structured light scanning



Phase-shifting with a static optical impression

Phase shifting is an interesting variation, that was introduced by Cerec. A tight mesh of light beams (between 10 and 50 microns, depending on the system) is projected. However, the mesh is static, meaning there is no sweeping. The handpiece (and camera) remain immobile whilst the projector shifts the mesh of light slightly on the arch (in dentistry the distance moved is $\pi/2$), (fig. 6). This method is known as 'phase shifting'. A 3D view of the captured object is constructed using a minimum of 3 or 4 captures of the slightly shifted mesh.
The patient must not move during the process, but this is fast: the operator can then move the scanner and start again. Since this is not a film, but a series of individual shots, I call this a 'static optical impression.'

fig 6 Electron-wave, phase-shifting interferometry



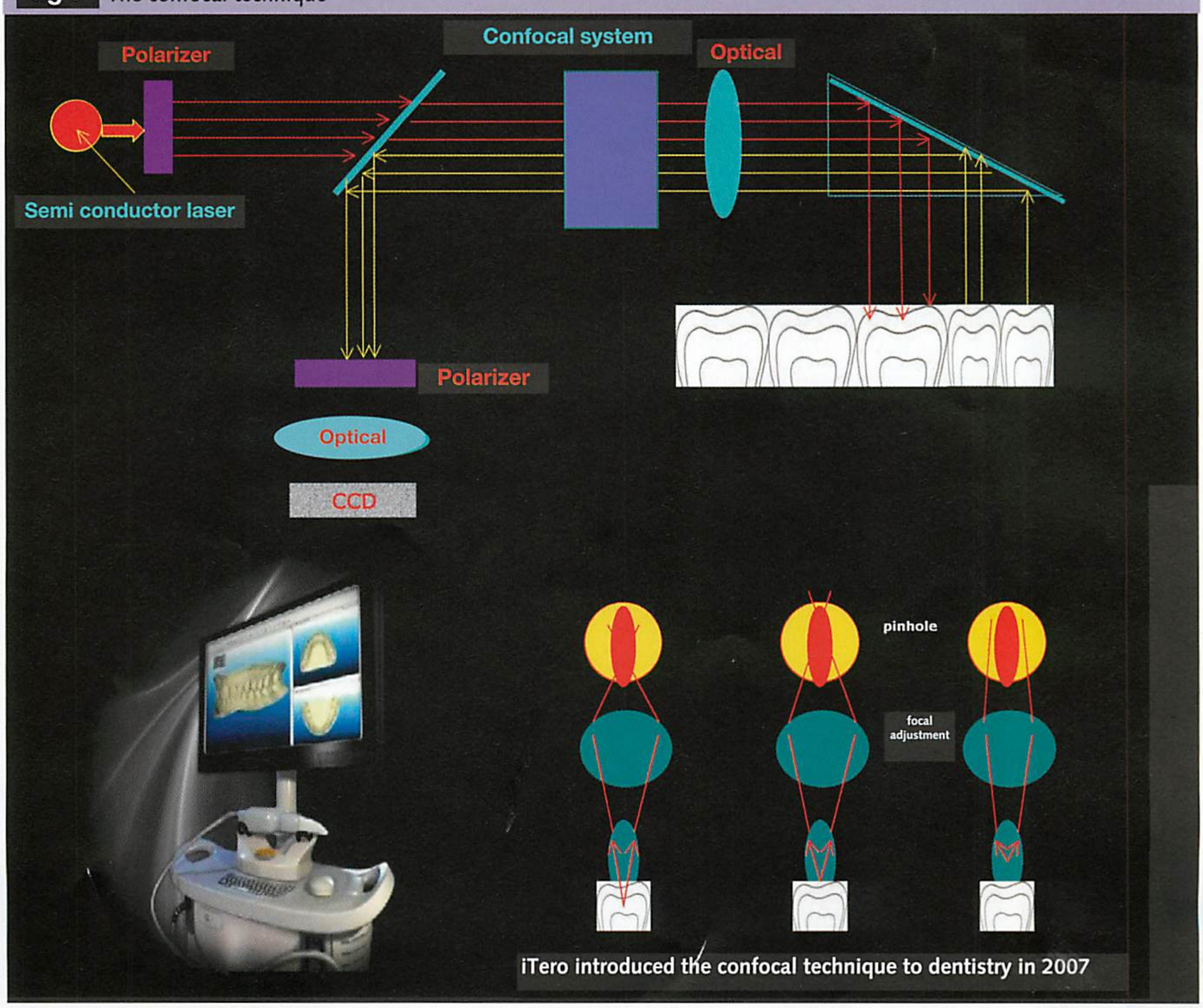
2 Confocal

The confocal principle was intially developed by Minsky in 1957, and was introduced into IOS technology by iTero in 2007 (fig. 7). This technique has since been taken up by other IOS manufacturers, including 3Shape. Systems using this principle capture optical sections by taking shots at varying field depths, like the layers of a scanner. This can be compared to slices of an apple that are put back one on top of the other to reform the initial shape. The precision can be exceptional because there are even confocal laser scanning microscopes (CLSMs).

The idea is to project between 100,000 and 300,000 of light onto the dental arch. Each beam will rebound when it hits a surface and be reflected back to the CCD. Absorbent lenses sweep the depth of field (DOF), moving the focal point from the lowest point (the gingiva) to the highest (the cuspal regions). If a beam of light is reflected from the surface and is well focussed, it will be intense enough to cross through the selective intensity filter. If the beam of light is out of focus (weak and dissipated), it will not pass through the filter.

Imagine burning a leaf with a magnifying glass: out of focus, the beam of light is large and not powerful enought to burn a leaf, but in-focus it is narrower, more concentrated, and powerful enough to burn the leaf. The beam of light disappears when it is out of focus. When it is in focus it crosses through the filter, which is a pinhole aperture, and then activates the CCD. The result is a cross-section of the dental arch, defined by the intensity of the reflected beams of light. This is a rapid and precise method.

fig 7 The confocal technique



3 Active Wavefront Sampling

“Active Wavefront Sampling combines triangulation with defocus of the primary optical system.”

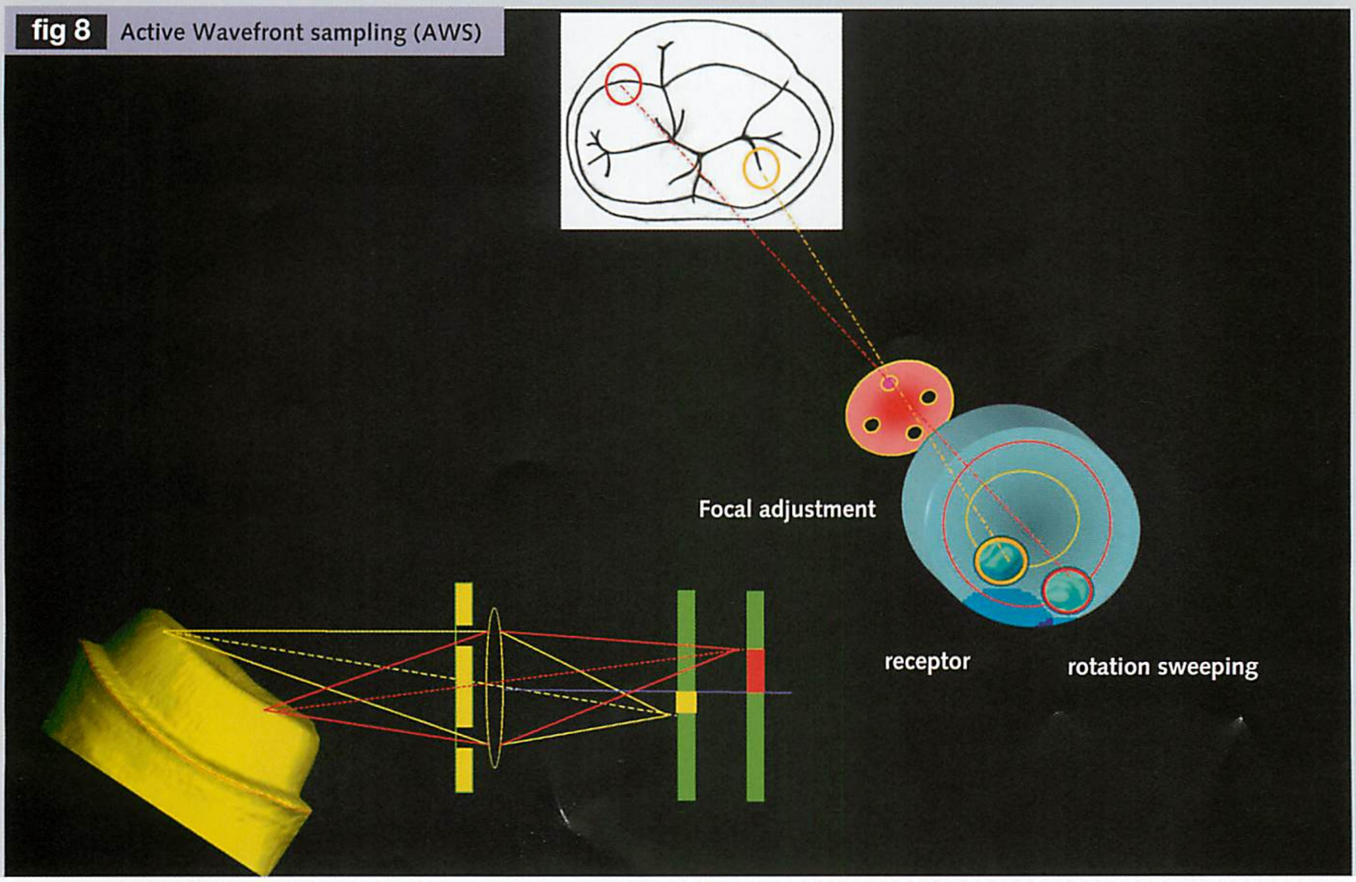
Introduced by 3M in 2007, the Lava Cos IOS was a case unto itself. It was the first dynamic digital impression scanner in dentistry to use a full motion (filmed) measuring method.

The technology uses Active Wavefront Sampling (AWS) principles, and was developed by MIT in Boston.
AWS combines the advantages of triangulation with depth measurement, based on the defocus of the primary optical system. The use of AWS principles meant the handpiece was small and easy to use in the mouth (fig. 8).
This intraoral scanning technique consists of aiming for a very specific zone of the dental arch and focusing the camera on this small area; since the area is small, the depth of field is reduced and so are the possible errors in calculating (z). The lense movement from point zero to the point of clarity is measured. This movement, which is the same as that which we use to focus a camera, indicates the distance between the CCD and the surface recorded on the CCD (hence the term ‘defocus of the primary optical system’).

The 3M IOS system uses this principle, but the operation is more complex than this - it also needs to calculate the distance according to the axis aimed for, using the position of the image on a spinning disk - but the basic principle remains the same. The operator moves over the arch with the handpiece, zone by zone, in order to capture the virtual model progressively.

NB: In 2019, 3M sold assets related to its intraoral scanner platform to Midmark Corporation. From April, 3M has discontinued sales of new systems in Europe and Asia Pacific. 3M will continue to provide data connections to trusted partners and dental labs, along with technical support for existing systems in these regions.

fig 8 Active Wavefront sampling (AWS)



4 Dynamic stereoscopy

Second Generation IOS systems

These systems are no longer based on the principle of measuring deformed light or varying the depth of field, but on the principle of spatial stereoscopy. Two images from slightly different angles are associated (with maximum overlapping) then analysed (like our brain would analyse a 3D object seen with both eyes). Another analogy is a space satellite, capable of reconstructing the Earth's surface in 3D. This is a type of triangulation without structured light. The difference is that a second generation IOS system, rather than using two cameras, is moved and observes the teeth like the satellite observes the Earth. This means that these systems must never be static. This is dynamic and automatic stereoscopy. In the same way that the satellite finds stable reference points (homologous points) which are common to the successive views (lakes, swimming pools, church spires...) the IOS also needs its reference points on the teeth. This complicated things, because there is not a structured light pattern on the teeth to refer to. (Bear in mind, making proportionally tiny movements far from the Earth is very different to making relatively big movements close to a tooth...) This means that this principle is not as simple as it may seem at first.

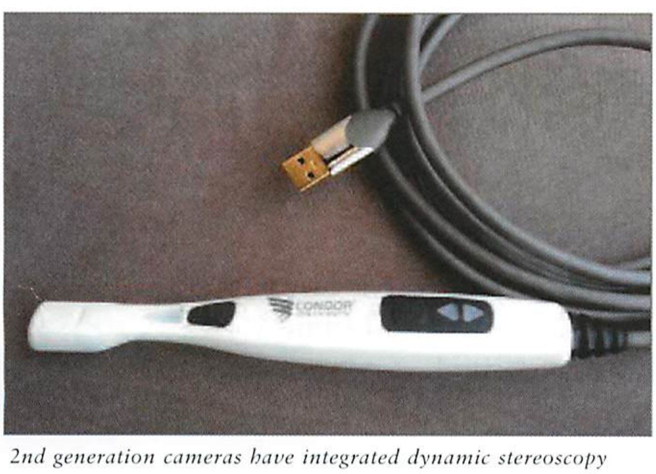
Finding homologous points on teeth took years of R&D, as well as complex mathematical formulae (this took over six years). This work paid off in the end.

The homologous points are identified in the very texture of the tooth: the micro-surfacing of the tooth is similar to the variations in the relief of planet Earth's surface, which serve as homologous points to the satellite between successive shots.

Second generation IOS systems are beautifully simple. Production costs have been considerably reduced and complex equipment for the projection and capture of structured light is no longer needed. The camera is an accessory (like in a mobile phone), and the light is simply needed to light the oral cavity.

In addition to these advantages, tooth colour is no longer an obstacle, but an aid. In contrast, stuctured light IOS systems have to reconstruct an impossible colour onto an object that has been measured using structured light.

The Biotech and Condor systems, the first of the 2nd Generation IOS systems, have integrated dynamic stereoscopy. This explains the lightness of the Biotech WOW wand and its simple design. The designers had to make the wand heavier, as it weighed less than 60 grams: too light for good scan stability. The software and image processing are the most important factors. This is in keeping with new generation computing design: the body is nothing, the head is everything. This allows for perpetual upgrades, like for the Windows operating system.



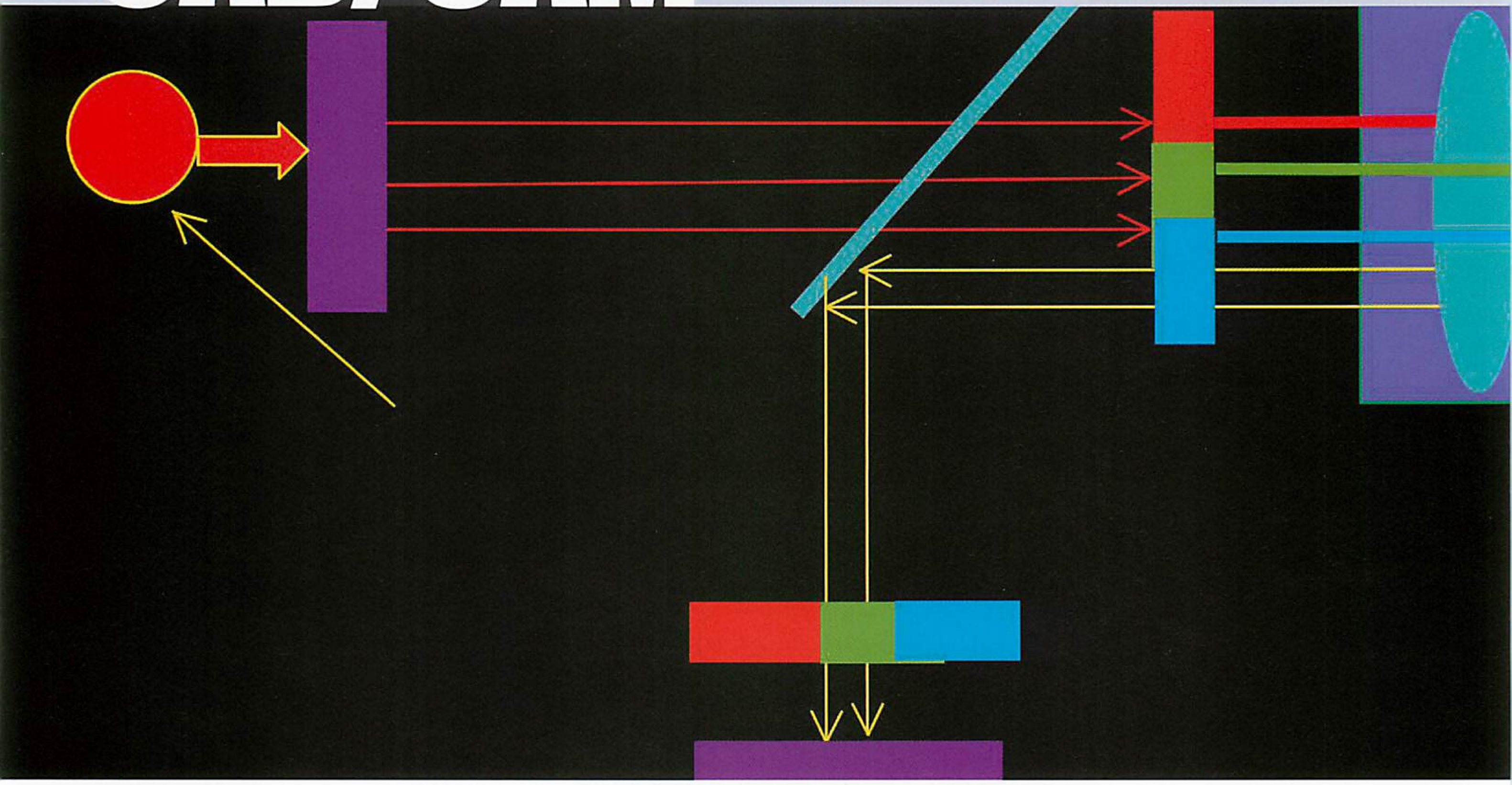
2nd generation cameras have integrated dynamic stereoscopy

Conclusion

This article has reviewed the four main types of technology that underpin the majority of IOS systems today, including the ways in which they have evolved. We have and attempted to provide a (popularised) explanation of how they work, which we hope you will find useful. The technologies vary in each system, and are associated with various harware and clinical measuring methods, making each system unique.

In our article overleaf (page 26) '*New IOS Technologies in 2019 / 2020*', we will discuss the latest developments in IOS Technologies, including the major trends we saw at the IDS 2019, developments in hardware and measuring methods, and the introduction of new hybrid systems seen at the IDS this year. What developments there have been!

François Duret &
Bruno Pelissier

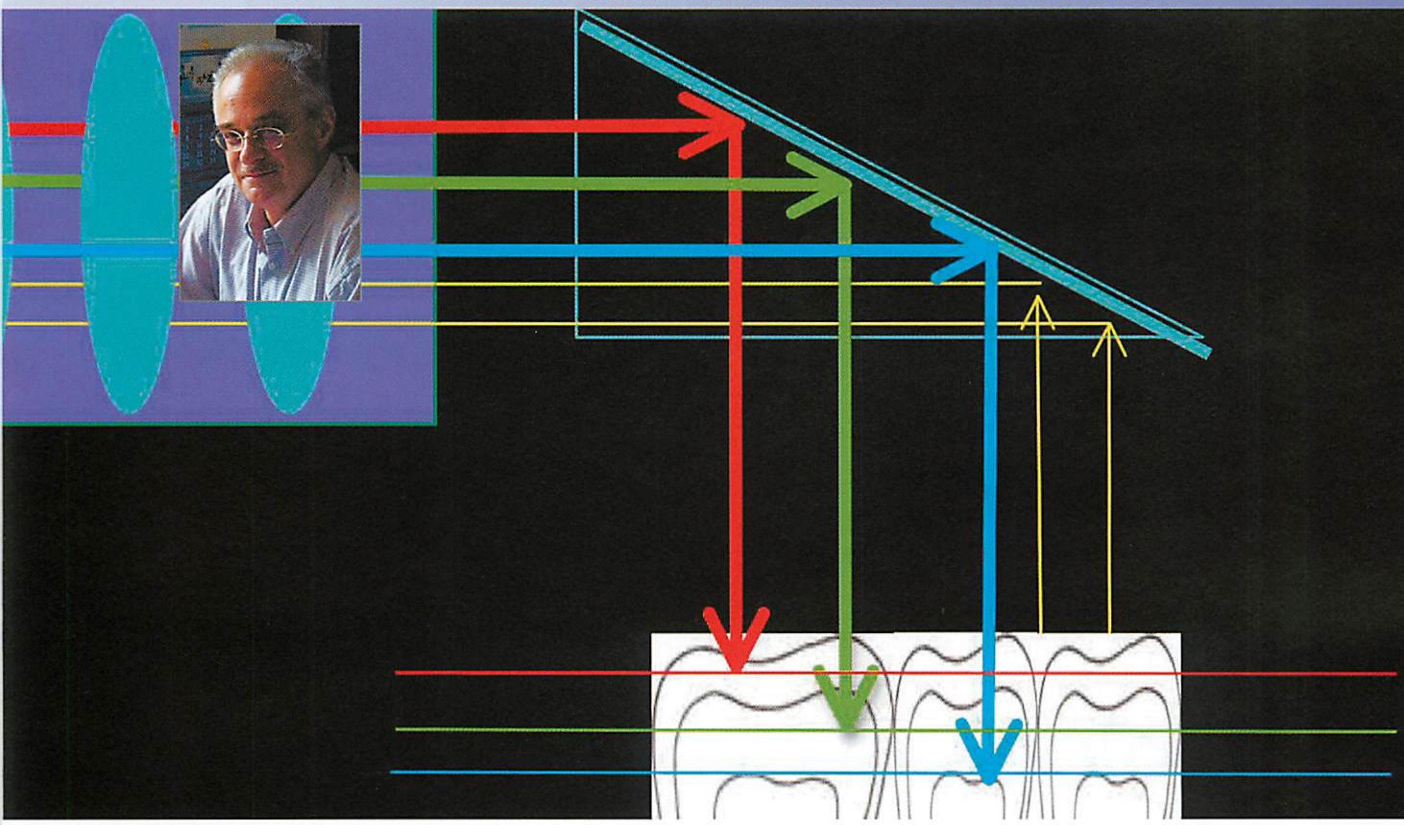


New IOS technologies in 2019 - 2020

An overview after the IDS

The IDS is always a good time to come together to update our knowledge in IOS technologies that are presented (or hidden in the machines). We have been doing this since 2004.

Prof. Francois Duret and Dr. Bruno Pelissier



1 Developments since IDS 2017

A plethora of systems

At first glance, the wide range of digital systems on offer is more striking than the technologies underlying the development of these systems. In 1995, these systems represented just 3 to 5% of the IDS exhibition, whilst today they represent over 85%. Nobody is fighting through the crowds to see the latest plaster trimmer - visitors want to see the latest scanner or cone beam device.

In this atmosphere, we discovered (and rediscovered) a wide range of dental CAD/CAM manufacturers and their offerings, including over 20 IOS (Intra oral scanner) systems (I counted 23) from around the globe. Processing software offer combines with this technology to offer ever more clinical solutions, as well as the possibility of piloting numerous subtractive (milling) and additive (stereo and fusion) machines.

Precision is the objective

The IOS systems featured in the comparative guide in this dossier had to answer to three imperatives: precision (single unit and full arch), the stability of the results (a good resolution) and the speed of capture which translates as ease of use.
The IOS concept was proved to be more than a utopian idea in the 80s and 90s. In the 2000s, it was demonstrated that these systems could be integrated into a dental surgery. This was largely helped by the integration of 'full motion' in the Lava system (3M) in 2007, which has since been widely adopted. The next stage, between 2015 and 2020, has been to ensure that the precision of these systems is adequate enough for dental uses, to establish that optical impressions are finally a credible alternative to the 250-year-old tradition of impression materials.
These objectives have now been met, but (other than 2nd generation systems) intraoral scanners are still a little heavy and cumbersome.

Outperforming physical impressions

Over the past three years, worldwide research has demonstrated that optical impressions offer results that are as good as, if not better, than traditional manual-chemical impressions. This research has been published in numerous respected scientific publications, such as JADA, JPD (Journal of Prosthetic Dentistry), The International Journal of Computerised Dentistry and Strategie Prothetique. It is generally recognised today that the precision of a digital impression for a single unit is between 20 and 40 µm (all segments taken together), and that the precision for a full arch is between 40 and 80 µm (for a slightly higher resolution). Some authors note - quite rightly - that the results vary between different systems, but the importance is minimal when you take into account that a red blood cell has a diameter of 8 µm, or that a metal crown can dilate by 10 µm when exposed to a hot drink!

In short, the objective has been achieved. But what about the technologies that have allowed us to obtain these results?

2 Technological evolutions over the past two years

At first glance (other than a few exceptions) the IOS systems presented at the IDS this year may appear similar to those presented at the IDS in 2017. But upon closer inspection, we can see that IOS systems have evolved much more than it would seem, and these developments have happened in three ways:

- Through the use of tried and tested technology (triangulation and structured light)
- Through the introduction of new ideas around a tried and tested technology
- Through a completely new concept which opens up new perspectives to IOS technology.

It should be noted that these three types of development have been made possible thanks to significant hardware developments (graphics boards, Graphic Processing Units (GPUs), cloud and hard drive storage, communication, miniaturisation, new captors and new LEDs).
It is complex to determine the underlying technologies used by each manufacturer, since they are keen to expound on the rapidity, simplicity and precision of their devices, but are surprisingly recaltricent when sharing information on their IOS technologies. Despite this, under the cover of what may seem to be 'technological monotony', there has been a deep shift. Now that precision has been mastered, the objective has changed.

Improving comfort and speed

The technological battle of 2019 is a different one: that of stability, the speed with which results are obtained, regardless of the method used or the tissues scanned, and most interestingly, the increase in the field of vision through the reduction of the angle used in triangulation.

The subject is becoming truly interesting, because we have moved on from an absurd micron competition to comfort in the mouth: high-speed capture, without hidden areas (shadow), preservation of the achievable precision and with a depth of field covering the whole mouth (superior to 30mm), with an increasingly small camera. Few manufacturers have achieved this for the moment, though they are all aiming for this now, whether they are aware of it yet, or not.

In 2021, the manufacturer who can offer an IOS with good precision at a field depth between 1 and 50 mm, with a small camera that does not necessarily use structured light, will finally offer dentists the possibility of comfortable handling in the mouth with no constraints, because we now work with real-time 3D colour reconstructions.

Main technological orientations

In our previous article on page 17 of this dossier, we discussed the evolution of IOS technologies up to the IDS 2017. The technological orientations noted here are a natural follow on from that article, and from our previous article published in D.T. Issue 96/97.

a) The advent of 'full motion'

One shot technology, a prerogative at the 2015 IDS in Cerec Bluecam or the 1st and 2nd generation of iTero is now obsolete, and almost all the IOS systems present on the market today use the 'full motion' capture method, developed by MIT and introduced by 3M in 2007. This has been possible due to the adaptation of existing softs, as well as the integration speed of the captors, the speed of transfer and processing, developments in graphics cards (which have been developed mostly thanks to gaming graphics) and techniques for storing images.

b) Colour for all

STL visualisation (in black and white or sometimes surface greyscale) is now always available with colour visualisation (essentially PLY format).

This development aids with diagnostic and is a good marketing tool, but it is does not change the underlying principles of optical impression technology, as it is more flattering than useful. In some cases it is virtual, because these days a good black and white captor and correct calibration allow your to create realistic colours. Due to the integration of software into Graphic Processing Units (GPUs), the onscreen display of surface modelling in colour (PLY format) and in real time has become standard for all quality IOS systems (Dentsply Sirona, 3Shape...)

c) Structured light vs. LED lighting and stereoscopic cameras

There are two generations of scanners. The first generation projects structured light. This technique was introduced by Hennson, in 1983. However, there are also now intermediate IOS systems that project pseudo structured light (random light). Second generation scanners no longer use structured light, but a standard LED light source (thereby bypassing the need for complicated and expensive structuring principles). This IOS technology was introduced by a French company in 2016 (Condor/Biotech).

3 Underlying IOS technologies and new developments

In order to understand the technologies today, it is essential to recall the underlying technologies in both first and second generation IOS systems:

A) Structured light (1st generation)

In first generation structured light cameras, there is a regular mesh, or pattern (composed of a multitude of evenly spaced points). When this mesh (pattern of light) is projected onto a tooth, the projected pattern is deformed by the surface angles of the tooth. It is the measurement (and complex calculations) of the changed position of the points in the mesh which allows for the measurement of the tooth. First generation scanners measure the deformation of the structured light on a tooth. The ongoing creation of this structured light in IOS systems is expensive, complex and fragile. However, this technology remains popular today. This principle is found in interferometric triangulation and confocal methods - meaning most IOS systems on the market today.

At the IDS this year, we noticed that this extant technology has become far more reliable - to an impressive extent. This is due to the use of new components, which have allowed designers to increase precision by speeding up the capture time (number of images per second), by modifying the projected patterns of light and refining the choice of wavelength (which paradoxically is tending more to red light).

Most of the IOS systems that were showcased by companies new to CAD/CAM use projected meshes (parallel lines) - which is the basis of the Fizeau interferometer (introduced to dentistry by Cerec 1). In contrast, a few well established IOS manufacturers are now offering interesting technical solutions. This undoubtedly explains the excellent clinical results that have been published over the past few years.

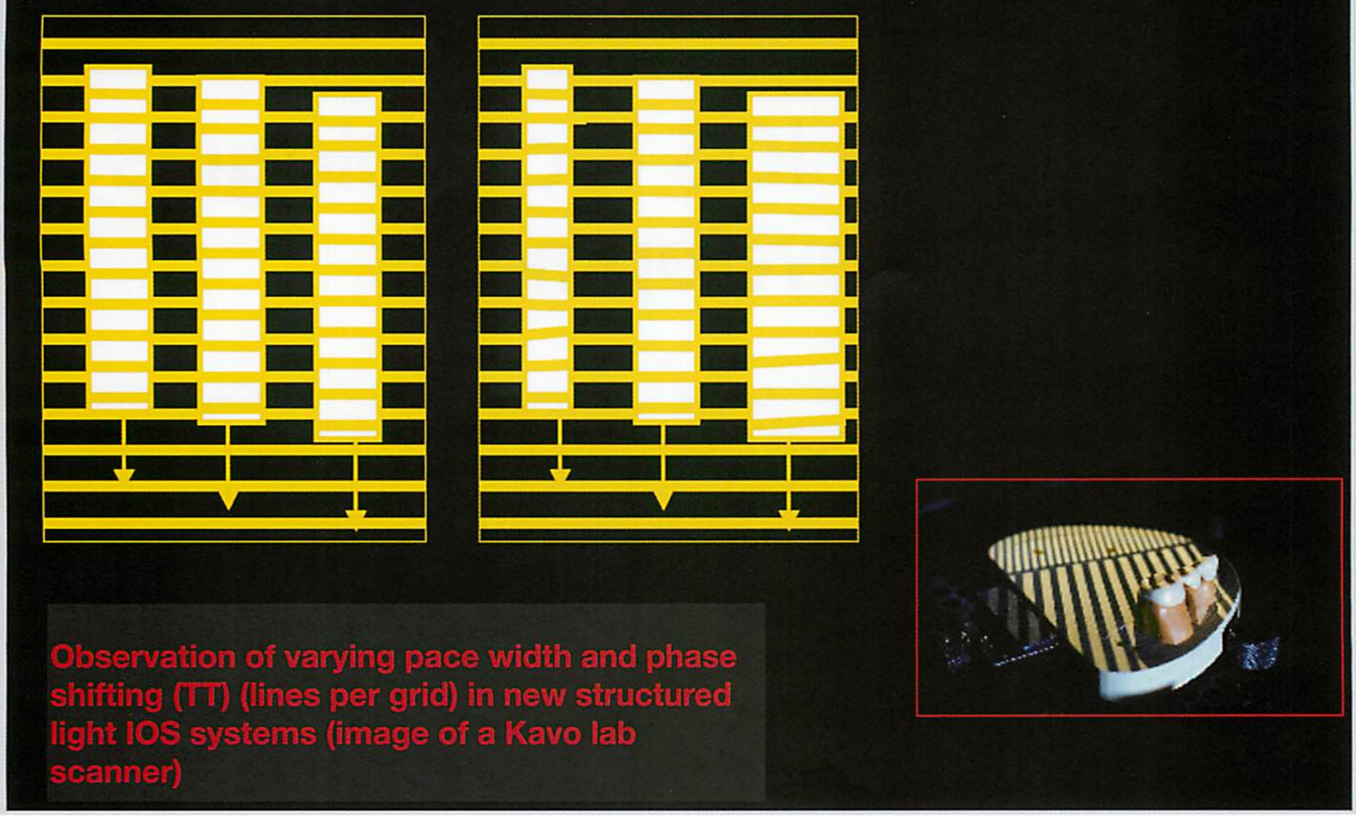
Multi-profile projection

We have observed a considerable increase in the precision of certain IOS systems using interferometric triangulation methods with structured light, (e.g. Carestream: 3500 vs. 3600).

How can we explain this unexpected development from a technological perspective? It is undoubtedly due to an increase in acquisition speed obtained with new captors and new graphics cards. Researchers have successfully projected not just one profile but several different profiles (in general with varying pace widths) and move them (shifting) on a single view (shot). This principle has been known since the research done by Fr. Duret et Martin D. Altschuler. By using this principle the precision can be improved from 80 µm to 30 µm without changing the principles of the IOS software (fig. 1).

This is a return to past technologies: this technology was used by Hennson in 1985 (phase shifting) as well as in numerous table top scanners in the 2000s (e.g. Kavo). Thanks to hardware developments, this is now overflowing into IOS systems, and I would not be surprised to see it used in several IOS systems at the IDS in 2021.

fig 1 Varying pattern profiles



Observation of varying pace width and phase shifting (TT) (lines per grid) in new structured light IOS systems (image of a Kavo lab scanner)

> **“Developers have improved precision by reducing the cross-section measurements from 100 µm to ... 50 µm...”**

Confocal: number of sections multiplied by ten and reduced dimensions

Even more interesting is the evolution in Confocal methods (developed from Mauguin's conoscopic methods). The developers of this technique in dentistry are iTero and more recently 3Shape. This concept, which was introduced by iTero, has the major advantage of combining the axis of projection and reflection (the term used is 'coaxial illumination'), which prevents any shadow effects, and also fixes the depth of field in accordance with the number of increments - that is to say, stages of measurement.

A confocal scanner works like an x-ray: that is, it works in successive 2D sections, by moving lenses on its focal plane. However, the beam (or structured light) rebounds off the dental tissues rather than going through them. The 3D object is reconstructed by layering the successive 2D sections on to each other (in the right order, of course!). For a further discussion on this, refer to page 23 of my previous article in this issue, '*Understanding IOS technologies and How they work*'.

In order to improve precision, developers have made the increments (the 2D sections) tighter. They have done this by reducing the 2D cross-section measurements from every 100 µm to every 80 µm and possibly even to every 50 µm or 30 µm for some systems. This has not been done by changing the underlying principles used by earlier IOS systems (discussed in my first article, '*How IOS technology works*' (page 17). Rather, it has been achieved by an increase in captor speed, buffer (a type of RAM) and 2D processing cards. This has meant that the number of layers (measured sections) has been multiplied by ten.

The size of hand pieces has also been reduced (fig. 2).

fig 2 Comparison of Lava (2007), Wow/Condor and iTero (2019)

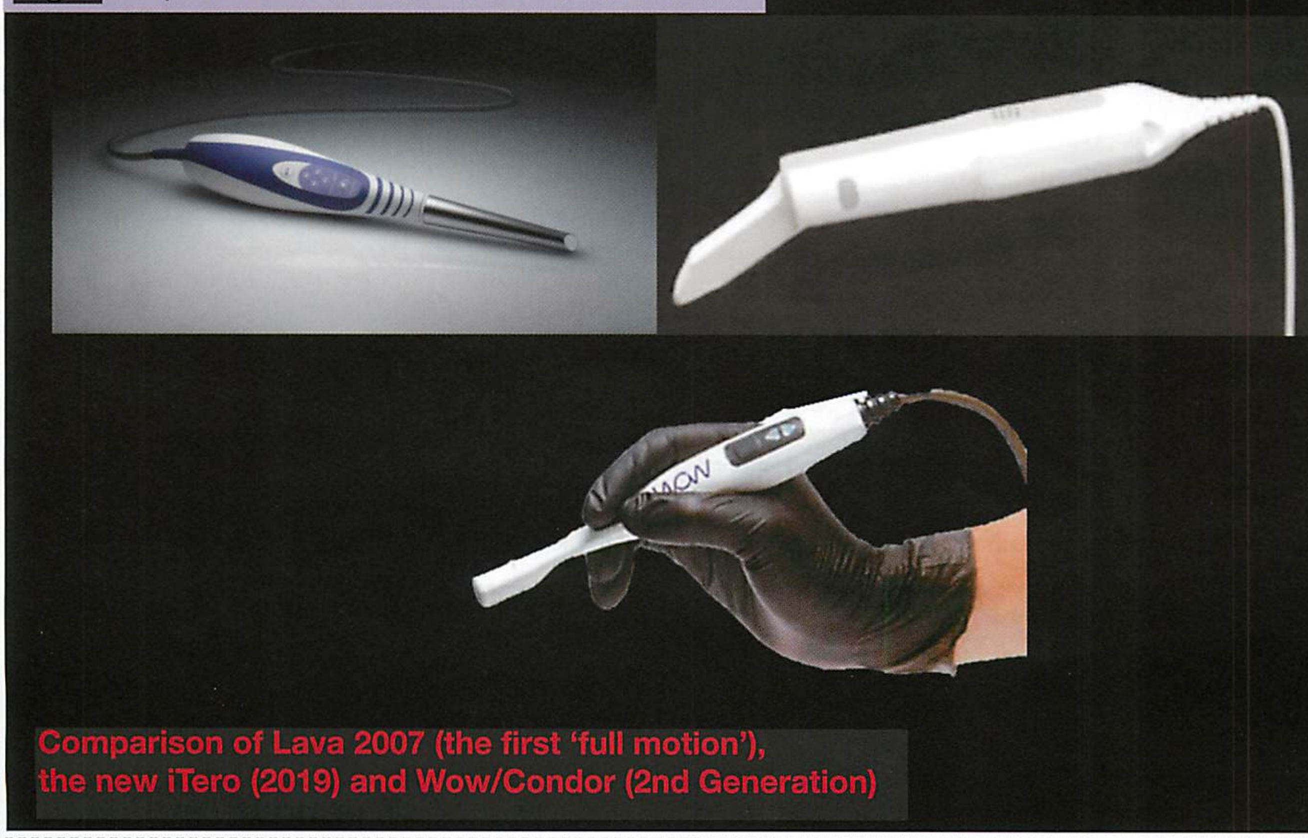
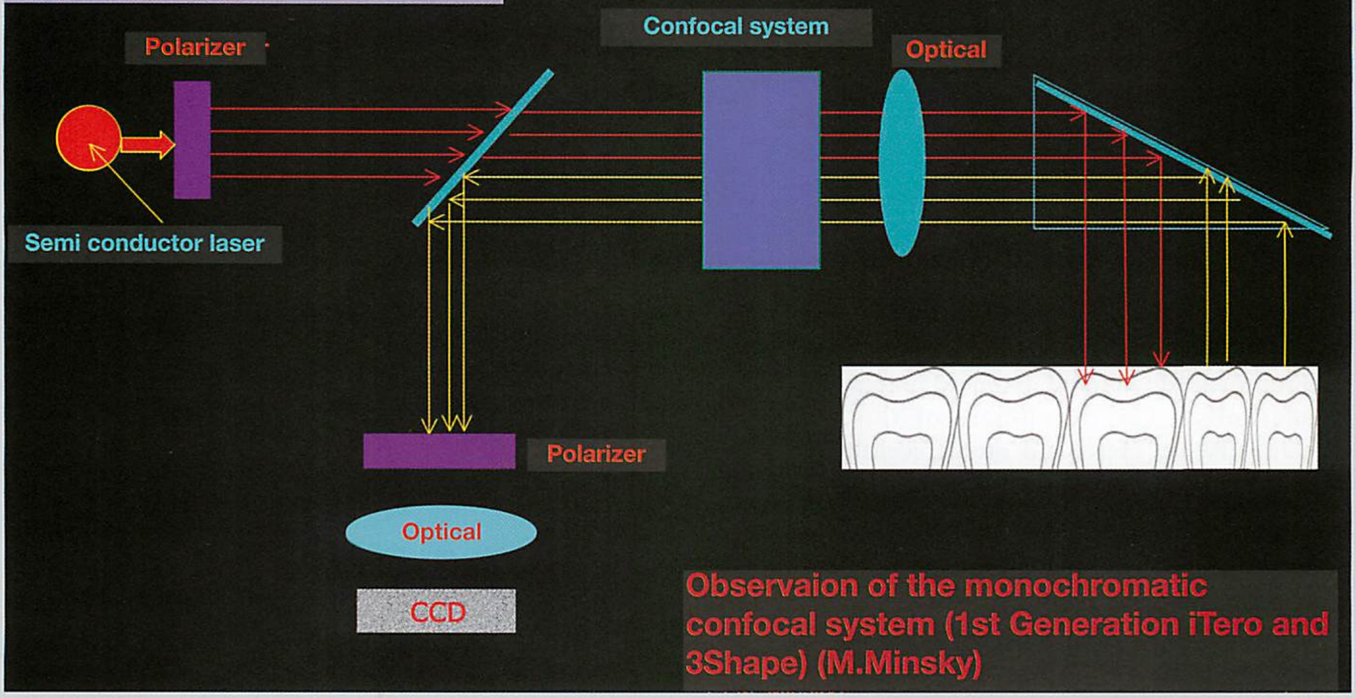


fig 3 A comparison of monochromatic ...



Polychromatic confocal and structured light

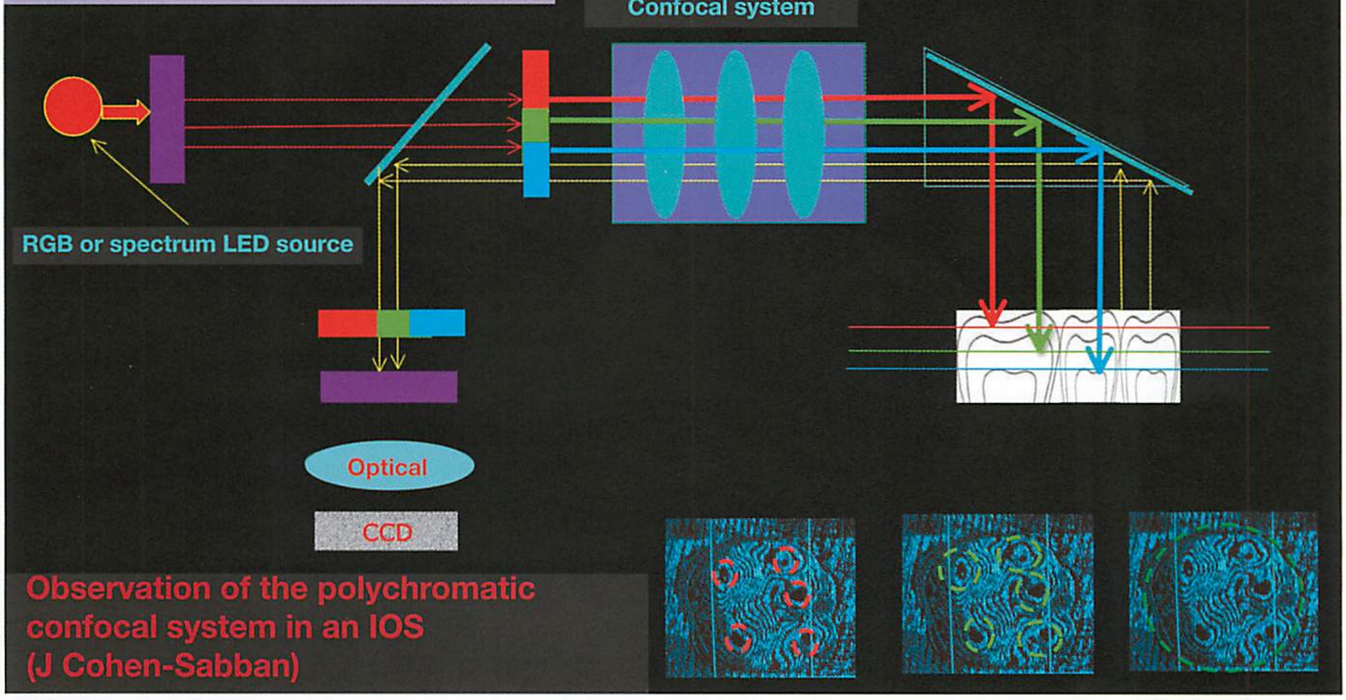
Without doubt this will be the arena for the hardware technology battles of the next generation of structured light scanners. Today the challenge is to surpass the classic confocal method.
Researchers and dentists have most certainly understood that the next step to conquering the hearts of dentists and technicians alike was to increase the field of depth whilst conserving precision - in any case, I hope this is the case, because it is a major factor for comfort in the mouth.

The problem that needs to be resolved is complex, because you must understand that the more a captor is above or below the focal plane, the more resolution and precision is lost.
This can mean dropping from a precision of 20 µm in the focal plane to 100 µm if the captor is 1 mm above or below the focal plane. This is therefore of great importance, and the mechanical movement of lenses that can be found in the iTero or the 3shape IOS systems have their limits, if the intraoral scan is to be done in a timeframe where the patient does not move.
An extremely interesting solution was proposed by the French researcher J. Cohen-Sabban in 1993.
He proposed changing the black and white confocal method (developed by Mr Minsky) to a polychromatic confocal method (conoscopy) (figs. 3 & 4).

The principle is as follows: instead of projecting a single structured light, a polychromatic light (in different colours, which can vary from three colours to the whole light spectrum) is projected on the tooth. Each colour corresponds to one of the 2D sections, and the colours are compiled on each other. Each colour can be comprised of sub-sections, which theoretically allows for the infinite multiplication of the number of sections.

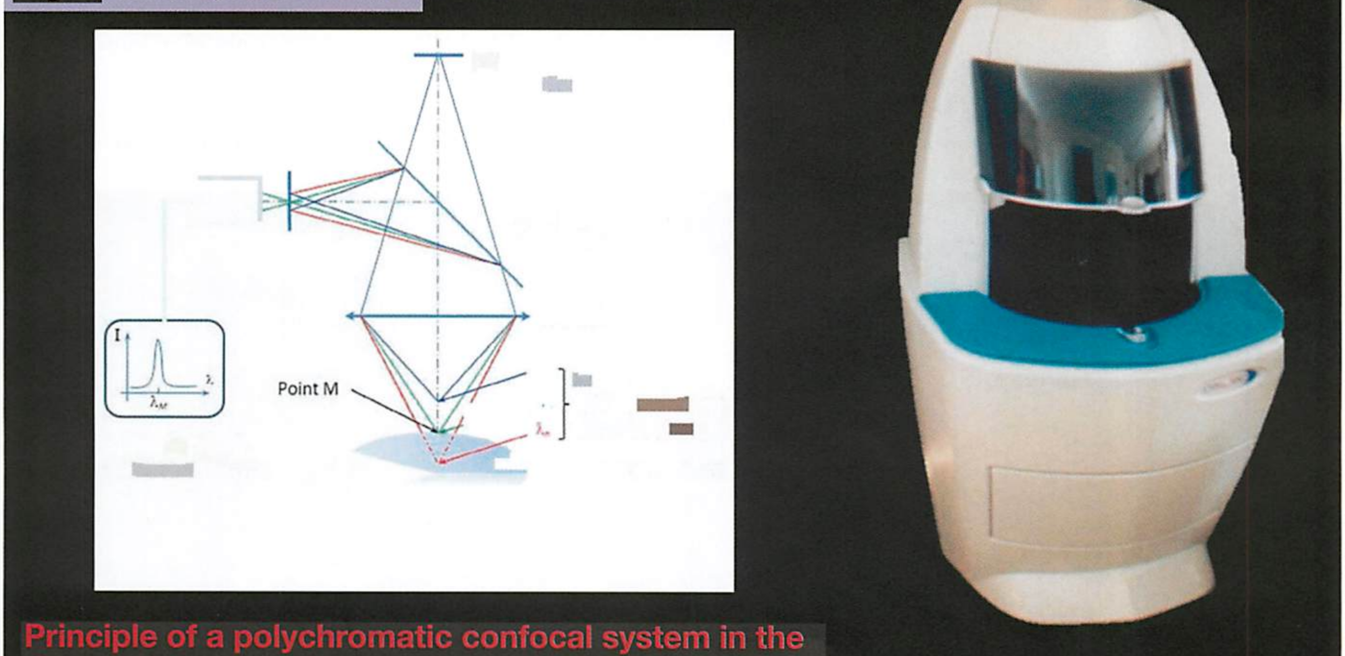
Cynovad's Pro 50 (lab scanner) in the 2000s (fig. 5), was already using the Cohen-Sebban principle, but at the time it was impossible to make it smaller (this is no longer the case today) and researchers did not see its value (alas, once again!).
This technological concept will benefit from today's increased captor speed and buffer memory capacity.
It will open up remarkable opportunities on all levels: both performance-wise and clinically.
I hope that my message will be heard, and will be researched and developed for IOS systems (there is already one manufacturer who seems very interested in these ideas).

fig 4 ... And polychromatic confocal methods



Observation of the polychromatic confocal system in an IOS (J Cohen-Sabban)

fig 5 Laboratory scanner Pro 50



Principle of a polychromatic confocal system in the Cynovad Pro 50 (J Cohen-Sabban)

The result is that we must maintain a precision of between 20 µm and 30 µm throughout a depth of field that is over 50mm to 70mm! Precision will be maintained throughout the mouth, regardless of the scanner position.

The greater the wavelength discrimination, the more layers there will be (and the greater the depth of field).

There is certainly a choice to be made between three antagonist factors - the number of sections, the scan time and the depth of field - but with a depth of 50mm in the mouth, the choice is simple, and two or three colours of light are sufficient.

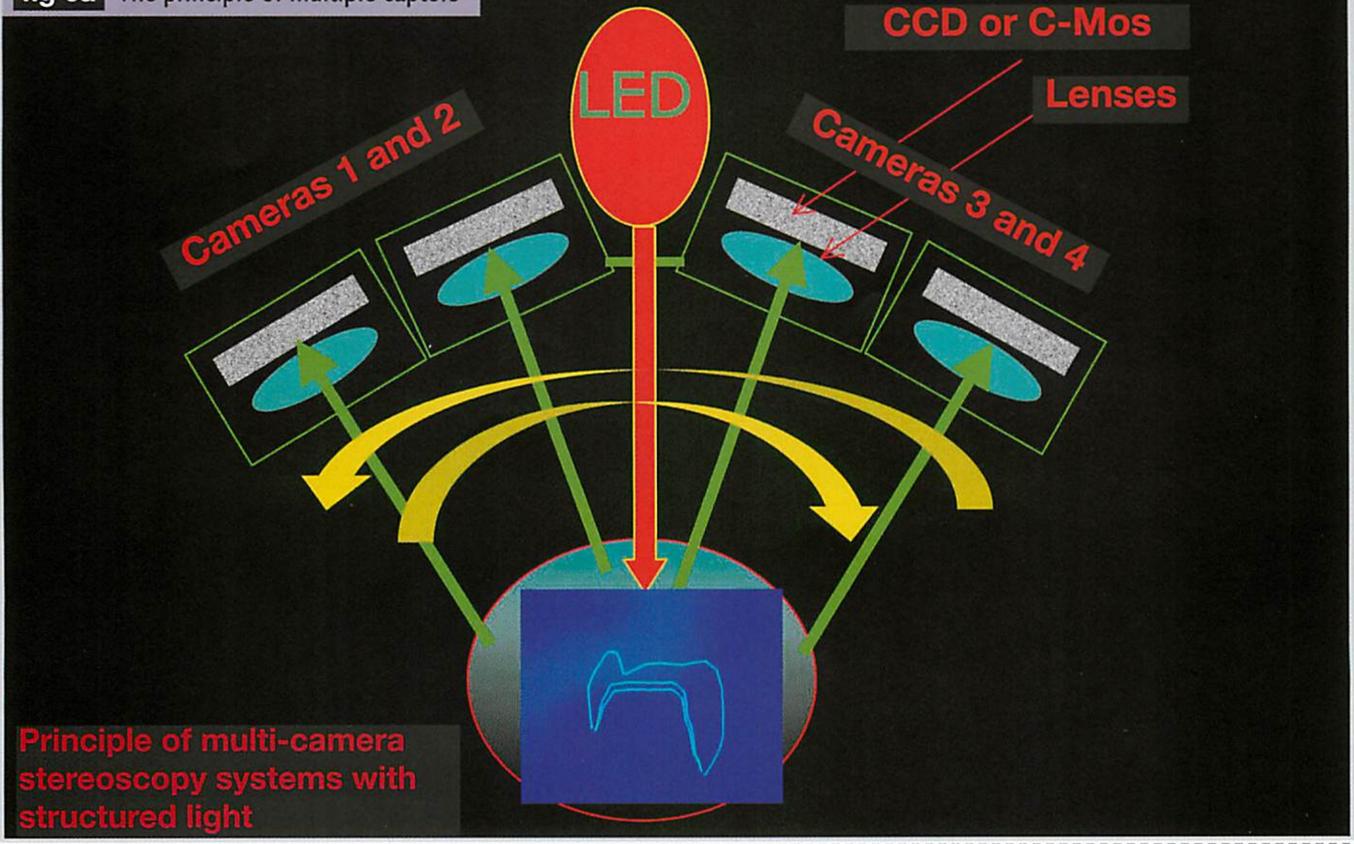
This is an interesting perspective for structured light!

B) LED lighting and stereoscopic cameras

Second Generation IOS systems have sought to free themselves of technological complexities that penalise the cost of IOS systems. They no longer project structured light, but use classic LED lighting to light the mouth, which, after all, remains ill-lit.
Since we no longer have a non-deformed reference point (in memory) with which to compare the same 'deformed' point on the tooth, another solution was needed. For this reason, second generation IOS systems apply principles of binocular vision (i.e. human vision). That is to say, we look at the point from two different angles, and through various calculations we can find its point in space (as our brain does). This technique took a long time to develop for dentistry due to the smooth surface of teeth, which made it difficult (even using algorithms) to locate and bring out these points on the labial surfaces, for example.
It was also difficult to master because there was no longer a common reference point, which was the source of structured light (common to the light before and after it was deformed).
Both cameras had to be positioned in relation to each other, and then during the intra oral scan, the spatial position of these cameras had to be identified - in relation to each other - because a single measurement of the point position was insufficient. How many pseudo scientists have underestimated the complexity of this task? Too many, I fear, as is often the case.
To simplify, the trick is to firstly identify a point using both the scanner cameras. When this point has been located, complex algorithms then calculate the supposed position of the camera that is observing it. It is a bit like in forensic science, when you trace the original position of a shooter by examining a bullet's trajectory through a body or in a wall.
When the theoretical positions of the scanner cameras, which observe the point, have been determined, the problem goes back to being a classic stereoscopic analysis (to be honest, it is much more complex than this... but it would take too long!). For further discussion on this you can refer to page 25 of my article on IOS technologies in this issue.

At the IDS 2019, there were only two cameras on the market that applied this principle without structured light: Biotech's Wow and Condor's Condorscan.

fig 6a The principle of multiple captors



> **“ This intermediate generation has become very popular in dental research labs today. ”**

The fact that no structured light is projected explains its small size and low weight, but many years of R&D were required to resolve the complex problem of point location without creating them artificially. This IOS technology is unique, even today, and due to the fact that no structured light is projected, it depends only on itself and its software. In my opinion, herein lies the future.

C) Intermediate IOS systems

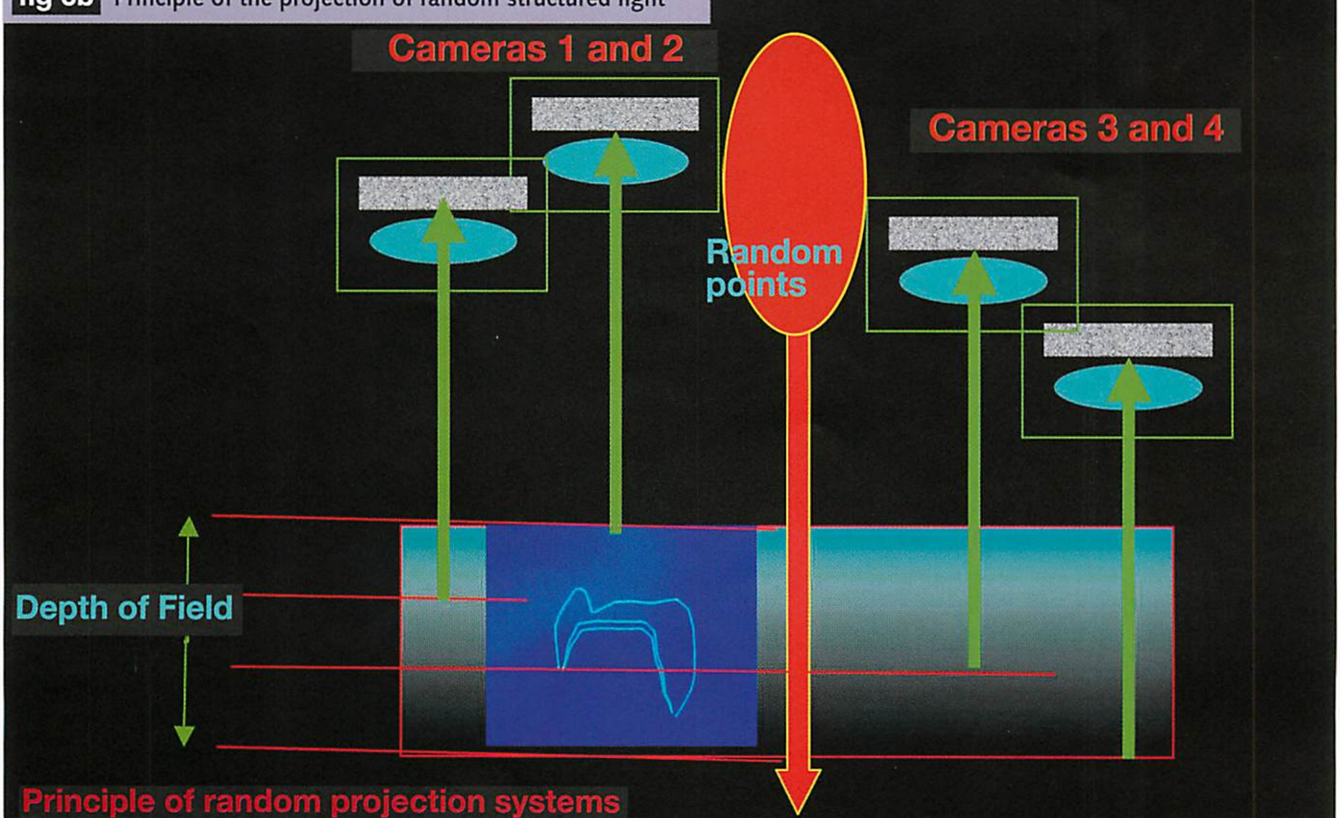
Faced with these fundamental and technological difficulties, certain IOS manufacturers have chosen intermediate solutions. There are therefore intermediate cameras, a blend of first and second generation IOS systems, which, due to their design, are still very reliant on the hardware for their performance.

The first of these was Dental Wings (and Steinbichler Optotecknik). Rather than identifying points on smooth surfaces, they create them artificially by projecting a random cloud of points rather than a regular complex mesh of points.
At the same time, mini cameras positioned at two different angles identify these points and measure their positions (fig. 6a).

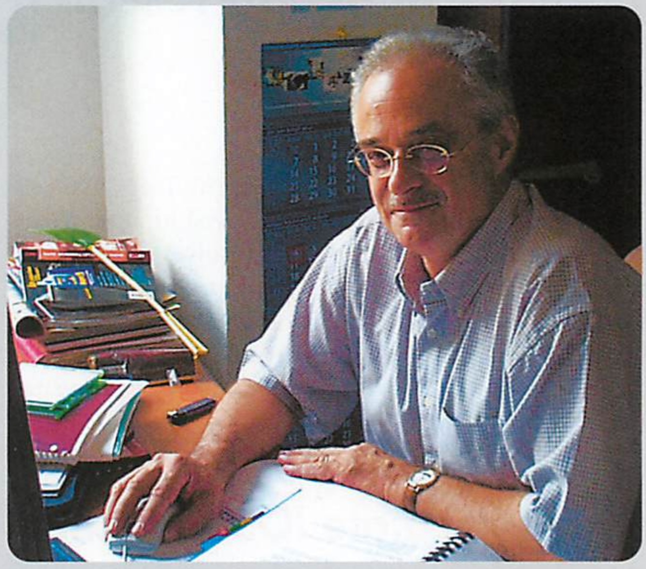
This 'intermediate' generation has become very popular in dental research labs today (Planmeca), as well as with upholders of Confocal methods such as 3Shape and Straumann.

Due to the miniaturisation of camera captors, they are working on the development of mixed stereoscopic / random cloud point projection with multiple mobile cameras (3Shape) or fixed and positioned at varying focal positions to cleverly increase the depth of field (Straumann) (Fig. 6b).

fig 6b Principle of the projection of random structured light



“ Future developments will focus on a reduction of hardware complexity... and in the increase of depth of field. ”



Conclusion

Now that ideal clinical precision and stability have been achieved for intraoral scanners, it seems to me, after the IDS 2019, that future developments will focus on a reduction of hardware complexity (through the progressive withdrawal of structured light techniques) and in the increase of depth of field.

New and additional IOS techniques
Other than certain applications, such as mandibular movements (4D dentistry), distance analysis and pressure (parodontology), shade analysis is becoming more frequent in IOS systems, and two systems also carry ‘caries detection’ technology.

Shade analysis is very useful for diagnostic purposes (PLY) but it remains unpredictable for restorative purposes (in particular for single tooth restorations). This is because it is impossible to take a correct shade reading if the method used is a colorimetric technique (3 base colours).

In order to record a shade accurately, a spectrocolorimeter technique would need to be used. Colorimetry, however many times the measurement is taken, always offers uncertain results due to the complexity of a tooth shade. Remember that it is impossible to apply the principles of elementary colour volumes (xyY) in these conditions and that there is a risk of metamerism (Duret, LQOS n°45).

Caries diagnostic using fluorescence (ultraviolet light) or thermal (infrared light) is an old technique. Numerous studies have used wavelengths in the attempt to detect dental plaque and caries or differentiate enamel from dentine. Simply adding a transmitter of a chosen wavelength (one more LED...) to an IOS scanner allows for the integration of these analyses.

From a technological perspective, which is the perspective of this article, this application is not difficult to understand, which is why we will not develop it further here.

We would also like to specify that all of the scanners discussed in this article can be used on a model in a dental lab, and the aim of the article was not to catalogue the various systems. Rather, this article aimed to focus on some of the technological trends, evolutions and techniques used in IOS systems today.
◆

François Duret
& Bruno Pelissier

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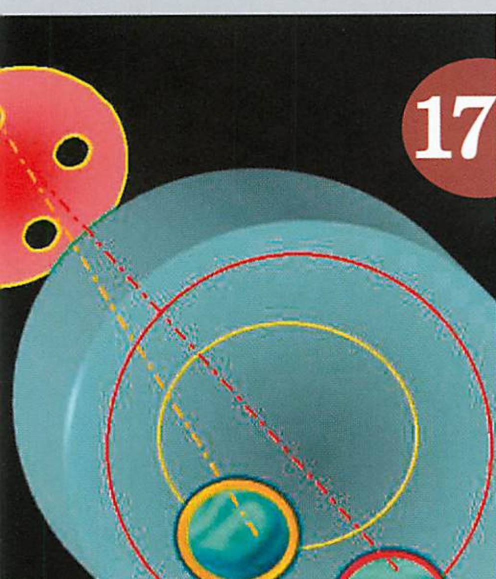

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