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Kompjuterom vođeno dizajniranje i izrada zubnih nadoknada - tehnologija „kompjuterizovanog otiska“

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Computer Aided Design and Manufacturing of Dental Restorations - "Computerized Impression" Technology

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KRATAK SADRŽAJ

CAD/CAM (kompjuterom vođeno dizajniranje / kompjuterom kontrolisana izrada) tehnologija u suštini omogućuje kreiranje dvodimenzionalnih ili trodimenzionalnih modela i njihovu materijalizaciju putem numerički vođenih mašina.Najvažniji segment izrade zubnih nadoknada pomoću sistema koji koriste CAD/CAM tehnologiju, predstavlja premeravanje preparacije zuba u ustima pacijenta ili na radnom modelu. Cilj rada je da prikaže mogućnosti i način funkcionisanja različitih sistema kompjuterom vođene inspekcije (otiskivanja), kao prvog segmenta svakog CAD/CAM sistema. Brojni istraživači su prezentovali različite pristupe metodi 3D skeniranja preparacije zuba. Kod jednoseansnih (ordinacijskih) metoda izrade zubnih nadoknada jedino su optičke metode skeniranja pružile zadovoljavajuće rezultate, dok laboratorijski sistemi i dalje koriste i mehaničke i optičke metode 3D skeniranja. Najvažnije osobine zbog kojih su optičke metode izrasle u lidera 3D skeniranja su: visoka preciznost, široko polje i brzina skeniranja, kao i ergonomija samog instrumenta.

Ključne reči: CAD/CAM, 3D skeniranje

SUMMARY

*CAD/CAM technology (**C**omputer **A**ided **D**esign / **C**omputer **A**ided **M**anufacturing) in the matter of fact helps in design and development of two-dimensional or three-dimensional models and their realization on numerical controlled machines. The key to direct or indirect CAD/CAM dental restorations is the mesurement of dental preparation in the mouth or on the plaster die. The aim of this paper is to describe the possibilities and the way of function of different computer aided inspection (CAI) systems as a first part of CAD/CAM systems. Different researchers have presented several approaches of methods for three dimensinal (3D) measurement. Today, for chairside dental treatment, only the optical method of measurement has lead to satisfactory results in practice. Laboratory CAD/CAM systems use mechanical and optical technologies for 3D measurement. Optical impression grows as a leader of CAI segment of almost every new CAD/CAM system. The most important properties of 3D scanners are: accuracy, volume and speed of measurement and ergonomy of instrument.*

Key words: CAD/CAM, 3D measurement

Ne tako davno primena kompjutera u stomatološkim ordinacijama, visoko razvijenih zemalja, je bila ograničena samo na administrativne i organizacione poslove (1). Iako je prva primena računara u jednoj medicinskoj ustanovi zabeležena još pre više od 30 godina, osetniji porast interesovanja za računarsku tehnologiju vezan je za kraj osamdesetih i početak devedesetih godina dvadesetog veka, a

Not so long ago the use of computers in dentist office, in highly developed countries, was limited to administrative and organisation jobs (1). Although the first application/implementation of computers in a medical institution was recorded almost 30 years ago, the increasing interest for computer technology was connected to the end of the 80s and the beginning of the 90s of the 20^{th} century, and povezan je sa razvojem PC računara (2,3). Već početkom 90-tih godina preko 70 % privatnih stomatoloških ordinacija u SAD koristi PC računare (4). Nesumljiva prednost ovakve organizacije posla je u povećanju brzine rada, komunikaciji sa pacijentima i smanjenju prostora za čuvanje podataka (5,6). Važna uloga je i u smanjenju mogućnosti unošenja pogrešnih, nelogičnih ili nekompletnih podataka (7,8). Ovakva primena računara predstavlja i danas daleko najprisutniji oblik korišćenja u našoj struci (9).

Sa godinama zahtevi stomatološke struke su se menjali i postajali složeniji pa su se računari, osim u menadžmentu, počeli primenjivati i u edukaciji (10-14), bazama podataka (15-17), ekspertnim sistemima (18), simulacijama (19-21), dijagnostici (22-26) i terapiji (27-31).

Primena računara u terapiji je predstavljala izazov entuzijastima i vizionarima koji su razvili čitavu novu oblast: kompjuterizovanu stomatologiju. CAD/CAM sistemi predstavljaju vrhunac računarske tehnologije sa mnoštvom realizovanih i potencijalnih primena u stomatologiji. Ove skraćenice potiču od engleskih reči Computer Aided Design / Computer Aided Manufacturing što u prevodu znači kompjuterom vođeno ili kontrolisano dizajniranje i izrada nekog proizvoda. U suštini ovi sistemi služe za kreiranje dvodimenzionalnih ili trodimenzionalnih modela i njihovu materijalizaciju putem numerički vođenih mašina.

CAD/CAM sistemi u stomatologiji sastoje se, u osnovi, iz tri komponente (36):

- prva komponenta je uređaj koji odslikava preparaciju zuba i druga potporna tkiva i zadužen je za prostornu digitalizaciju podataka (CAI- Computer Aided Inspection);
- druga komponenta se sastoji iz kompjutera na kome sa planira i proračunava forma tela nadoknade što odgovara području CAD-a;
- treća komponenta predstavlja numerički upravljanu frez mašinu koja iz osnovnog oblika izrađuje zubnu nadoknadu što odgovara CAM području.

Po pravilu tu su preporučljive i dodatne dorade kao što je poliranje ili individualizacija od strane zubnog tehničara ili lekara (33).

Kompjuterom vođena inspekcija - prostorna digitalizacija

Slično kao i kod konvencionalnog načina rada, ključ preciznosti izrade zubne nadoknade izrađene CAD/CAM tehnikom predstavlja "kompjuterizovani otisak". Za prostornu digitalizaciju manuelno obavljene preparacije opisane su različite metode. Uglavnom se one mogu svrstati u dve osnovne grupe: mehaničke i optičke metode (34).

- Mehaničke metode prostorne digitalizacije

Mehanička metoda je dobila ime po fizičkom kontaktu delova skenera i objekta merenja. Princip rada mehaničke metode prostorne digitalizacije zahteva prisustvo mernog alata (pipka-merne sonde) pomoću koga se "opipa" mereni predmet u pojedinim tačkama. Merni senzor se sastoji iz dva osnovna dela i to "merne glave" i sistema

it was connected with the development of the PC-s. (2,3). At the beginning of the 90s over 70% of the private dentist offices in the USA used PC-s. (4). The advantage of this kind of organization of the work was, undoubtedly, the increasing the working speed, communication with the patients and lessening the space for the data storage (5,6). The important role was in a reduction of entering wrong, illogical and incomplete data (7,8). This kind of computer use presents, by far, the most common form of computer use in our profession (9).

During the years the demands of dentist profession were changing, becoming more complex, so the computers, except for the management, started to apply in education (10,14), data bases (15,17), experts systems (18), simulations (19-21), diagnostics (22-26) and therapy (27-31).

The computer use in a therapy is a challenge for enthusiast and visionaries who developed a whole new field: computerised dentistry. CAD/CAM systems present the top of computer technology with lots of realised and potential applications in the Dentistry. Those abbreviations stand for English Computer Aided Design/Computer Aided Manufacturing. Basically, those systems are used for creating two-dimensional or three-dimensional models and their materialisation through numerically led machine.

CAD/CAM systems in dentistry consist, basically, of three components (36):

- The first component is the device which picture the preparation of teeth and other support tissues and it is responsible for the area digitalisation of the data (CAI-Computer Aided Inspection);
- The second component consists of computer which plans and calculate the form of the reparation body which belongs to the area of CAD;
- The third component presents the numerically conducted milling machine which makes tooth reparation from the base shape which belongs to the area of CAM;

It is recommended to do the additional work as polishing and individualisation by a dental technician or a dentist (33).

Computer leaded inspection - area digitalisation

The key to the precision of making tooth reparation with CAD/CAM technique is "computer print", similarly as in a traditional way of work. For the area digitalisation of manually done preparation different methods were described. They could be classified into two main groups: mechanical and optical methods (34)

- Mechanical methods of area digitalisation

Mechanical method got the name according to the physical contact of the parts of the scanner and the objects of measurement. The principle of work for the mechanical method of area digitalisation demands the presence of the measuring tool (touch-camera sound), which "touches" the measuring object in certain points. The measuring senza prihvatanje mernih pipaka. Sonde mogu biti različitih veličina, kružnog su oblika (rubinske kugle), i u svakom slučaju moraju biti prilagođene veličini merenog objekta. Na bazi tako dobijenih mernih tačaka formira se geometrijski oblik.

Na kvalitet merenja mehaničkim skeniranjem, u tehničkom smislu, utiče veliki broj parametara. Među najvažnijim su: veličina glave sonde, pritisak sonde na objekat merenja, dužina ručice, osetljivost indukcionih senzora, pokretljivost glave skenera, korak merenja odnosno broj mernih tačaka po jedinici površine i softver. Kod dugačke ručice linearno pomeranje puta vrha sonde dovodi do manjeg odstupanja od šarnirskog merača ugla nego kod kraće ručice. Iz ovog razloga metode sa dužim ručicama su bolje sa stanovišta mogućnosti premeravanja većeg prostora, ali moraju imati mnogo osetljivije merače ugla (35).

U zavisnosti da li se senzor 3-D skenera pokreće rukom ili motorom izvršena je podela mehaničkih metoda prostorne digitalizacije na manuelne i automatske.

Manuelne metode mehaničke prostorne digitalizacije, danas, imaju samo istorijski značaj. Ograničenje predstavlja potrebno vreme da bi se svaka pojedinačna tačka koja se očitava digitalizovala. Automatske metode skeniranja nesumljivo imaju prednost nad manuelnim zbog lakšeg, bržeg i preciznijeg rada.

Druga podela mehaničkih metoda prostorne digitalizacije je prema kriterijumu prostora gde se skeniranje obavlja. Razlikuju se intraoralne i ekstraoralne metode.

Osnovni princip mehaničkog trodimenzionalnog opipavanja (skeniranja) u stomatologiji opisao je i patentirao 1977. god. Mushabac (Mushabac D.R.: US Patent Documents, 4 182 312, 1977). Ova metoda je predstavljala intraoralnu mehaničku manuelnu digitalizaciju (34). Za merenje je korišćena stomatološka sonda koja se rukom pomerala po ispreparisanoj površini zuba. Ova metoda je zahtevala da se držač mehanizma fiksira za zubni niz. Predlog je bio da se koristi jedna modifikovana kašika za otiske u koju se stavi gips za uzimanje otiska (Sl. 1). Ova metoda nije doživela praktičnu primenu. Realizovana upotreba ovog sistema u stomatologiji bila je samo u grubom merenju otoka mekih tkiva posle operacije.

sor consists of two main parts: the “measuring head” and the system, which accepts the measuring tentacles. Sounds could be of different sizes, they have round shape (ruby balls), and, in any case, should be accommodated to the size of the object measured. Based on in such a way achieved measuring points, the geometrical shape is formed.

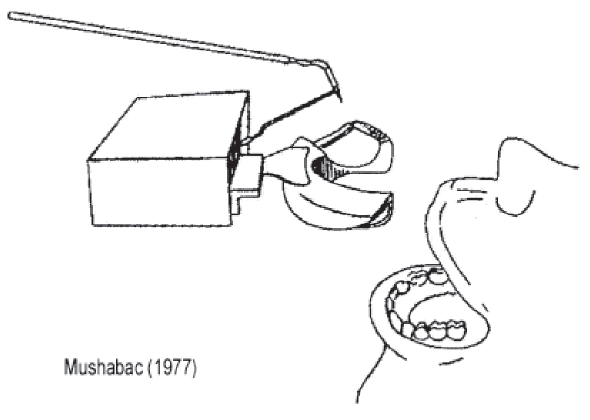
Great number of parameters influence, technically, on the quality of mechanical scanning measurement. The most important are: the size of the sound head, the pressure of a sound on object of measuring, the length of the handle, the sensitiveness of inductive sensors, the mobility of the scanner head, measuring steps, namely the number of the measuring points per surface unit, and software. When the handle is long, linear movements of the sound top lead to the small exceptions from the hinge angle measuring that when the handle is shorter. This is the reason why the methods with longer handles are better from the standpoint of possibility of moving in the larger space, but they should have more sensitive angle measuring (35).

Depending on that, if a sensor is moved by a hand or a motor there is made a division of mechanical methods of area digitalisation on mechanical and automatic.

Manuel methods of mechanical area digitalisation, nowadays, have only historical importance. The limit is time needed to digitalise each point that is read. Automatic methods of scanning undoubtedly have an advantage over the manual because of the faster and more precise work.

The other division of mechanical methods of area digitalisation is according to the area where the scanning is done. There are intra-oral and extra-oral methods.

The main principle of mechanical three-dimensional touching (scanning) in Dentistry was patented by Mushabac in 1977. (Mushabac D.R.: US Patent Documents, 4 182 312, 1977). This method presents an intraoral mechanical manual digitalisation (34). For measuring there was used dentist sound that was manually moved on the prepared surface of the tooth. This method demanded to fix the holder for the teeth row. The proposition was to use a modified teeth spoon for imprints in which the plaster for imprints was put (picture 1). This method didn't have its practical application. The realised usage of this system in dentistry was only in rough measuring of tissue swelling after the surgery.



Slika 1. Manuelna mehanička intraoralna metoda 3D skeniranja primenjena kod Mushabac metode
Figure 1. Manual mechanical intraoral method 3D (Patent by Mushabac)

Intraoralno mehaničko skeniranje je imalo tu prednost u odnosu na optičke sisteme što je moglo da digitalizira subgingivalna područja.

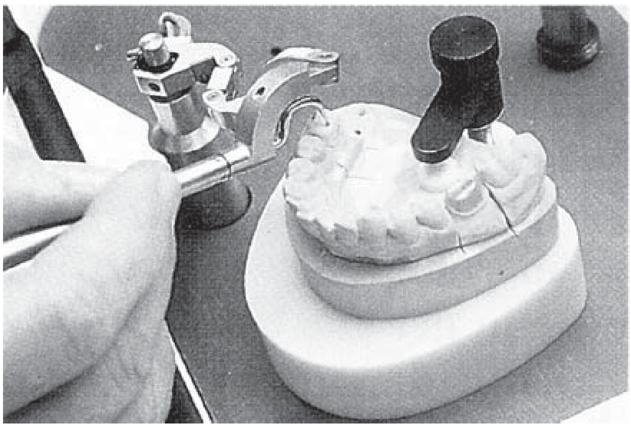
Danas se koriste samo ekstraoralne mehaničke metode. Njihovom razvoju najviše su doprineli:

- DentiCad-sistem (BEGO, Bremen) (Rekow 1991.) (36) - sonda skenera je sa šest šarnira bila povezana za ručicu a od njih su tri šarnirske ose sadržale elektronske merače ugla, a preostale su povezivane sa vrhom sonde i mogle su se pomerati (Sl. 2). Za merenje uglova korišćeni su detektori magnetnog polja, takozvani Hall senzori. Kontakt mernog instrumenta sa površinom zuba kontroliše se pomoću kompjutera, a pomeranje sonde se obavljalo manuelno.

Intra-oral mechanical scanning had its advantage to the optical systems that it could digitalise sub gingival areas.

Nowadays, only extra-oral mechanical methods are used. Those who helped the most to their development are:

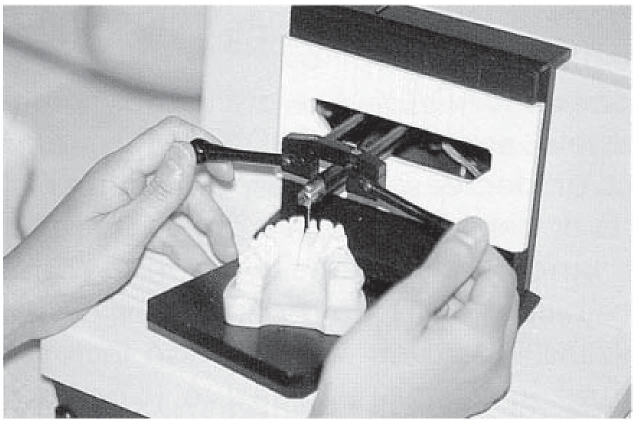
- DentiCad system (BEGO, Bremen) (Rekow 1991.) (36) – the scanner sound was connected to the handle with six hinges, and the three of them consist of angle measurer while the others were connected to the sound tip and could be moved (picture 2). For the angle measuring there were used the magnetic field detectors, so-called Hall sensors. The contact of the measuring device with the tooth surface was controlled with computer help, and the moving of the sound was manual.



Slika 2. Manuelna mehanička ekstraoralna metoda 3D skeniranja primenjena kod DentiCad sistema
Figure 2. Manual mechanical ekstaoral methods (DentiCad - system)

- DCS Precident sistem (Austenal; DCS Dental AG /CH/ i DCS Dental systeme /D/; www.dcs-dental.com) (37)- takođe koristi manuelnu mehaničku digitalizaciju (Sl. 3). Dužina ručice i mogućnost pomeranja sonde je toliko velika da je, prvi put, bilo moguće premeriti ceo model vilice, što je dalo mogućnost izrade većih mostova. Druga prednost je bila ta da se trodimenzionalna morfologija preparisanog zuba mogla lako rekonstruisati sa ograničenog broja mernih tačaka. Senzor je bio dijametra od 1 mm a dužine 10 mm. Vreme potrebno za digitalizaciju je bilo oko 15 minuta.

- DCS Precedent system (Austena; DCS Dental AG/CH/ and DCS Dental system /D/; www.dcs-dental.com) (37)- also used manual and mechanical digitalisation (picture 3). The length of the handle and the possibility of sound moving was very large so it is possible, for the first time, to measure the whole model of a jaw, which enable making of the larger bridges. The second advantage was that the three-dimensional morphology of the prepared tooth could be easily reconstructed from the limited number of measuring points. Sensor had the diameter of 1mm and the length of 10mm. The time needed for digitalisation was 15 min.



Slika 3. Manuelna mehanička ekstraoralna metoda 3D skeniranja primenjena kod DCS Precident sistema sa mogućnošću premeravanja celog modela
Figure 3. Manual mechanical ekstaoral methods (DCS Precedent system) with the possibility of measure the whole model

- Procera (Nobelbiocare; www.nobelbiocare.com) (38) predstavlja jedan od poslednjih sistema koji još uvek koristi, ali i razvija metodu ekstraoralnog mehaničkog skeniranja. Različite generacije skenera su prošle od faze manuelnog, preko automatskog skeniranja samo jednog patrljka, tročlanih mostova, pa do poslednje generacije automatskog skenera koja može skenirati polje do 5 zuba. Danas su u prodaji: Procera Picolo (slika 4) koji je dobrim karakteristikama, smanjenom dimenzijom i nižom cenom doveo do masovnije primene ovog sistema i Procera Forte, skener visoke rezolucije kojim je prošireno polje primene ovog sistema.

- Procera (Nobelbiocare; www.nobelbiocare.com) (38) presents one of the last systems, which has been still used, but it also develops the method of extra-oral mechanical scanning. Different generations of scanner has passed the phases from manual, through automatic scanning of only a stump, three parts bridges, till the last generation of the automatic scanner which can scan an area of 5 teeth. Nowadays there are sold: Procera Piccolo (picture 4) which, with its good characteristics, small dimensions and lower price led to the mass application of this system and Procera Forte, the scanner of the high resolution which enlarged the field of the application of this system.

Slika 4. Procera Picolo skener (levo) i Procera Forte (desno)
Figure 4. Procera Picolo scaner (left) and Procera Forte (right)

Procera skener poseduje mehanizam za automatsko kretanje senzora koji je safirna kugla. Kugla klizi po površini cirkularnim pokretima. Pritisak na površinu zuba je veoma mali, od 15 do 20 grama. Za ceo tok skeniranja potrebno je od 3 do 5 minuta po patrljku, i za to vreme skener registruje minimum 20.000 do 50.000 mernih tačaka.

Bez obzira na rešenje mehaničkog trodimenzionalnog skeniranja, moraju biti ispunjeni određeni preduslovi. Sve površine preparisanog zuba moraju biti glatke, zaobljene i dimenzija koje su prilagođene veličini glave skenera. Posebno su karakteristični oblik preparacije okluzalne površine i njeni zaobljeni prelazi u aksijalne. Demarkacija najčešće mora biti oblika izraženog polužleba. Na taj način se delimično usklađuje oblik preparacije sa tehničkim mogućnostima skenera. Na pokretnom radnom patrljku demarkacija mora biti tako obrađena da ne ometa nesmetano i kontinuirano klizanje sonde po površini gipsanog modela, i sve podminirane površine moraju biti ukonjene.

Kod novijih generacija CAD/CAM sistema uglavnom se primenjuju različiti oblici optičke prostorne digitalizacije koje, u stomatologiji imaju najdužu tradiciju.

- Optičke metode prostorne digitalizacije

Pionirski korak ka CAD/CAM tehnologiji u stomatologiji povezan je sa optičkom metodom prostorne digitali-

Procera scanner has a mechanism for the automatic sensor movement, which is a sapphire ball. The ball slides on the surface in circular movements. The pressure on the teeth is very easy, 15 to 20 grams. For the whole scanning coarse it is needed 3 to 5 minutes per stump, and during that time the scanner registries minimum of 20.000 to 50.000 measuring points.

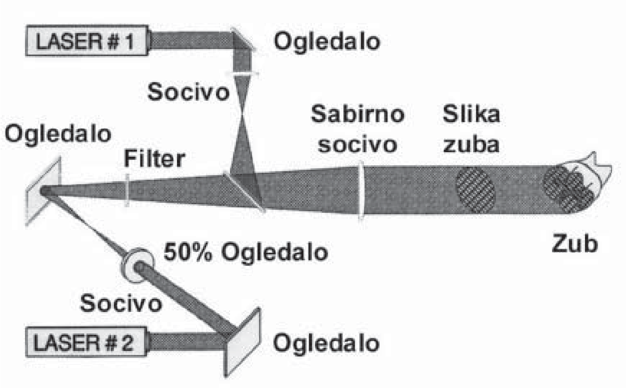
Disregarding the solution of the three-dimensional scanner, have to be fulfilled the certain pre conditions. The each surface of the prepared teeth have to be smooth, rounded and of the dimensions accommodated to a scanner head. Especially peculiar is the shape of the occlusal surface preparation and their rounded transition into axial. Demarcation line is often has to have the shape of an outstanding half-gutter. In that way, the shape of preparation and technical abilities of the scanner are partly coordinated. On the moving working stump the demarcation should be processed in such a way not to disturb continuous slide of the sound on the surface of the plaster model, and all undermined surfaces have to be removed.

At the new generations of the CAD/CAM systems the different sorts of optical area digitalisation is applied, which have the longest time of application in dentistry.

- Optical methods of area digitalisation

The pioneer step towards CAD/CAM technology in dentistry is connected with optical method of area digitalizacije. Doktor Bruce Altschuler je predstavila holodontografiju još 1971 godine (39). Prvi put je izneto da otisak zuba može biti prikazan kao kombinacija računarske tehnologije i laserske holodontografije (Sl. 5). Optički “otisak” je izvođen pomoću dva snopa laserske svetlosti čiji su zraci proizvodili hologram. Ove informacije su pružale kompjuteru mogućnost da kontroliše rad frez mašine koja bi iz bloka zlata izfrezovala krunicu. Ove mašine bi se nalazile u malom broju centralnih laboratorija. Koliki je vizionarski značaj ovog rada govori i činjenica da je još tada autor dao predlog da se okluzioni profil može generisati pomoću holograma dobijenog od antagonista ili od holograma funkcionalnog registrata centralnog položaja mandibule i lateralnih kretnji. Autor je takođe predlagao primenu ove tehnologije i u izradi proteznih ploča od akrilata.

sation. Doctor Bruce Altschuler presented holodontography back in 1971. (39). It was stated for the first time that the teeth imprint could be shown as a combination of computer technology and laser holodontography (picture 5). The optical “imprint” was made with the help of two laser light beams, which made hologram. That information supplied a computer with possibility to control the work of the milling machine, which could cut the crown from the gold block. Those machines would be situated in a small number of central laboratories. What was the importance of this visionary work said the fact, that back than the author had a proposition to generate the occlusive profile with the help of hologram that was got from the antagonist or the hologram of the functional registrant of the central mandible position and lateral movements. The author proposed the application of this technology in production of acrylate denture tiles.



Slika 5. Osnovni princip funkcionisanja Holoodontografije po Altschuler-u
Figure 5. The basic principle of holoodontography (Altschuler)

Ideja doktora Bruce Altschulera, u izvornom obliku, nikada nije zaživela u praktičnoj primeni, ali je predstavlja ideju vodilju za sve kasnije CAD/CAM sisteme.

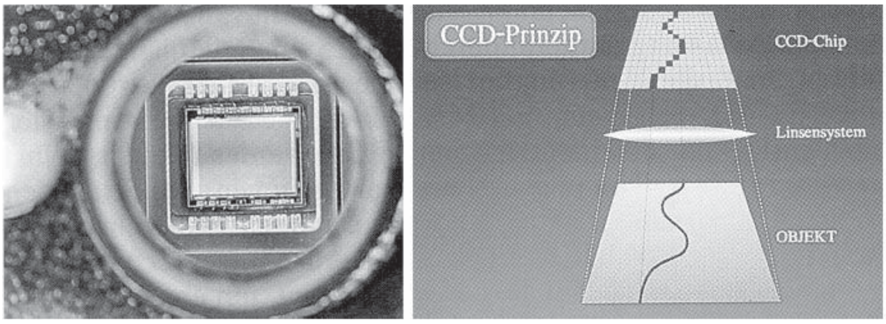
Trodimenzionalni vid čoveka zahteva: najmanje 2 oka, CNS za obradu dobijenih podataka i neku vrstu stečenog znanja o relativnim odnosima i veličinama predmeta. Danas su kompjuteri, u mogućnosti da simuliraju ovakve procese analize slike. Nažalost to se ne odnosi, u potpunosti, na predmete koji imaju relativno slabo izraženu teksturu, kao što je ljudski zub. Za ovakve predmete u praksi se koristi nekoliko sistema manje ili više različitih od ljudskog vida.

Praktično rešenje otpičke digitalizacije, danas, predstavlja snimak preparacije pomoću takozvanog CCD čipa (Charge - Coupled - Device), koji je inače sastavni deo svih video kamera (Sl.6). Osnovna namena ovog čipa je da konvertuje ulazni signal, koji predstavlja određena količina svetlosti u električnu struju određene voltaže. CCD čip se sastoji iz velikog broja svetlosno osetljivih tačaka na slici, takozvanih Piksela (minimalni gradivni elemenat svake slike). Oni su raspoređeni u redovima i kolonama. Gustina mreže, a time i rezolucija dobija se iz broja tačaka slike u jednom redu ili koloni CCD čipa. Rezolucija odnosno razlučivost se može definisati kao maksimalan broj ulaznih podataka po jedinici dužine.

The idea of Doctor Bruce Altschuler has never had its practical application in its original shape, but it was a leading idea for every latter CAD/CAM systems.

The three-dimensional eyesight demands: at least two eyes, CNS processing of the received data and some sort of acquired knowledge about the relative relations and sizes of objects. Nowadays the computers are capable to simulate those processes and pictures. Unfortunately, it is not related fully to the objects that have weakly expressed texture, as human tooth. For those objects I couple of systems are used practically that are more or less different from the human eyesight.

Practical solution of optical digitalisation nowadays, presents the snapshot of the preparation with the help of CCD chip (Charged-Coupled-Device), which is anyway the part of all camcorders (picture 6). The basic purpose of this chip is to convert input signal, which is presented by a definite quantity of light in electrical power of a certain voltage. CCD chip consists of great number of light-sensitive points on the picture, so-called Pixels (minimal material elements of every picture). They are arranged in rows and columns. The thickens of a net, and so the resolution, too, is got from the number of the points in one row or a column of a CCD chip. The resolution, so to say, identification can be defined as a maximum number of input data per the length unit.



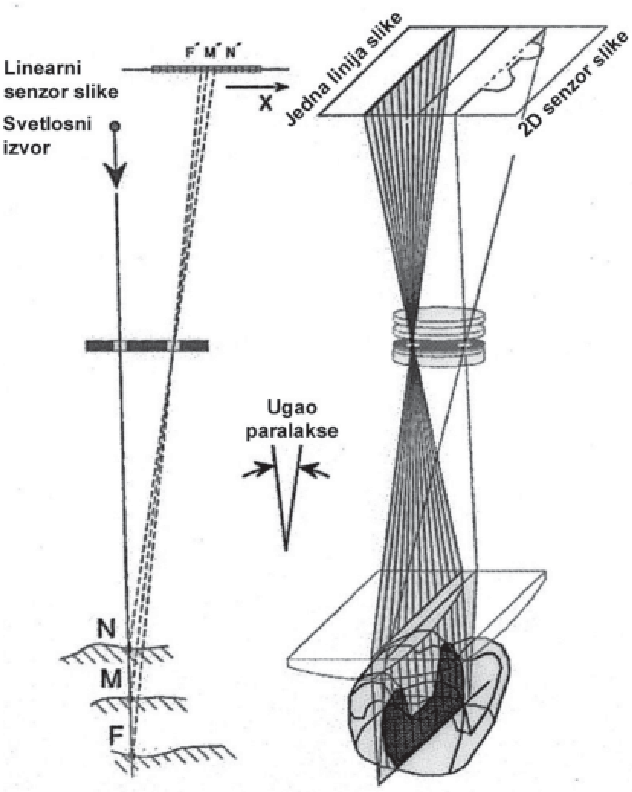
Slika 6. Uveličan CCD čip i njegov osnovni princip rada
Figure 6. CCD - chip - the basic purpose

Ako se, na primer, slika preko jednog zajedničkog sistema sočiva projektuje na CCD čip u svakom pikselu oslobodiće se impuls struje određene voltaže. Veličina oslobođene voltaže odgovara prisutnoj svetlosti na određenoj tački slike. Da bi se utvrdila voltaža iz svakog piksela električni impuls se mora transportovati do elektronike za ocenjivanje. Kada se izmere električni impulsi u svakoj tački slike dobija se digitalno oslikavanje. U jednom pikselu se može utvrditi samo svetlost jedne tačke na slici.

Izlazni signali iz CCD čipa daju samo dvodimenzionalni prikaz slike. Za prostorno prikazivanje mora biti izmerena i vertikalna dimenzija. Za tu svrhu se koristi stari princip takozvane Moire-topografije. Jedan linijski svetlosni zrak projektuje se na objektu. Ako se posmatra ova svetlosna linija iz drugog pravca, uz poznatu konstantu paralakse, pomoću trigonometrijskih odnosa dobija se i podatak o visini svake pojedinačne tačke (postupak aktivne triangulacije Sl. 7).

If, for example, a picture is projected through a mutual system onto CCD chip, each pixel will release an impulse of a certain voltage. The size of released voltage corresponds to a present light on the certain point of a picture. To establish voltage from each pixel, an impulse must be transported to the evaluation electronics. When the electric impulses are measured in each of the pixels the digital picture is acquired. The light of only one point on the picture can be set in one pixel.

The output signals of CCD chip give only two-dimensional picture. For the spatial presentation a vertical dimension should be measured. For that purpose, it is used the old principle of so-called Moire-typography. One line beam of light is projected on an object. If this light line is observed from the other angle, with the known constant of parallax, and with the help of trigonometry relation, the datum of the each particular point height is achieved (active triangulation proceeding (picture 7)).



Slika 7. Princip dobijanja 3-D slike kod spot skenera
Figure 7. Active triangulation preceeding

Osnovna karakteristika svakog CCD čipa predstavlja njegova rezolucija. Ako se želi dobiti slika nosača sa njegovim agonistima potrebno je najčešće skenirati predeo od 16mm dužine. Preko sistema sočiva se svetlost prenosi do CCD čipa. Ako se izračuna odnos dužine skeniranog predela i broja piksela u najčešće korišćenom čipu vidi se da se na svakom pikselu odslikava deo od 20 mikrona. Pošto tačnost merenja iznosi samo polovinu od ulaznih vrednosti, iz toga rezultira da je tačnost skeniranja 40 mikrona. Ova tačnost bi bila dovoljna, ali nažalost ukupna preciznost za CAD/CAM izradu nadoknada dobija se uvek iz sume pojedinačnih grešaka svakog segmenta tako da ukupna tolerancija postaje veća nego postignuta tačnost optičkog skeniranja.

Optičke metode prostorne digitalizacije se, slično mehaničkim, na osnovu kriterijuma prostora gde se skeniranje obavlja, dele na intraoralne i ekstraoralne metode. U odnosu na veličinu polja skeniranja klasifikuju se na tačkaste i trakaste (površinske).

Intraoralno skeniranje podrazumeva rad u stomatološkoj ordinaciji, dok su ekstraoralne metode, uglavnom, vezane za rad u laboratoriji. Obe metode su se paralelno razvijale, ali danas u praktičnoj primeni se nalazi samo jedan intraoralni (dva su u najavi) i veliki broj ekstraoralih sistema. Zahtevi koji se pred njima postavljaju su različiti.

Iz ergonomskih razloga intraoralni skener ne bi trebao da se fiksira na preostale zube. Ovaj zahtev utiče na njegov oblik, veličinu, težinu i mogućnost održavanja higijene, ali pre svega na brzinu skeniranja. Iskustveno je dokazano da uvežban korisnik može držati glavu skenera nepomično naspram zuba koji se skenira, najviše 0.5 sekunde. Podatak o brzini akvizicije podataka merenja, pored rezolucije, predstavlja jedan od najvažnijih u izboru sistema i njegovoj širokoj primenljivosti. Veličina polja koje se skenira je minimalno 14x14 mm, a optimalno 25x14 mm. Raspon dubina skeniranja bi morao biti najmanje 10 mm, a ne bi smeo biti veća od do 14 mm. Rezolucija skenera bi trebalo da bude najmanje ±25μm (40).

Najpoznatiji predstavnik intraoralne optičke metode je Cerec sistem (Sirona Dental Systems GmbH; www.sirona.de) (41). Kod ove tehnike koristi se više svetlosnih zraka, u obliku linija, projektovanih na preparaciju (linijski šrafirana površina). Zraci se u brzim oscilacijama pomeraju preko objekta tako da se u toku kratkog perioda dobija trodimenzionalni oblik preparacije. Slično konvencionalnoj fotografiji kamera se u trenutku snimanja mora, što je moguće mirnije držati. Fiksiranje kamere nasuprot objektu kod ovog sistema nije neophodno jer je vreme potrebno za obradu podataka iz svih 340 000 piksela manje od 0.5 sec (Sl 8). Tokom 2005. godine prikazana su još dva intraoralna skenera Evolution 4D i HintEls, ali oni još uvek nisu ušli u serijsku proizvodnju.

Kod intraoralnog optičkog skeniranja pojavio se problem refleksije svetlosti sa površine tvrde zubne supstance. Time se svetlo-tamni kontrast projektovane linijski šrafirane površine preopterećuje. Rešenje ovog problema

The resolution is the main characteristic of each CCD chip. If we want to get a picture of a carrier with all of its antagonists it is needed to scan the 16mm long part. Through the lenses system the light is transferred to CCD chip. If the relation of the scanned area length and the number of the pixels in the mostly used chip is calculated it will be seen that that each pixel picture a part of 20 microns. Since the exactness of the measurement is only the half of the input values, it results in the scanning exactness of 40 microns. This exactness would be enough, but, unfortunately, the total precession of CAD/CAM construction of the reparation is always got from the sum of individual mistakes of each segment so that the total tolerance grew bigger the achieved exactness of optical scanning.

Optical methods of area digitalisation are divided, like mechanical, according to the area where the scanning is done, to intra-oral and extra-oral methods. According to the size of the scanning area they are classified into spotted and striped (surfaced).

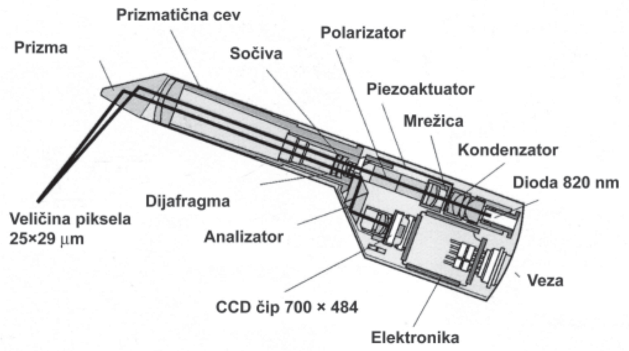
Intra-oral scanning means the work in a dentist office, while the extra-oral methods are mainly tied to laboratory work. Both methods have been developed side by side, but nowadays, only one, intra-oral is practically used (two are announced) and a great number of extra-oral systems. Demands set for them are different.

Intra-oral scanner shouldn't be fixed on the other teeth for the ergonomic reasons. This demand influences its shape, size, weight and hygiene, but before all, it influences the speed of the scanning. It is known, from the experience, the practised user can keep the scanner head immobile in front of the tooth scanned, mostly for 0.5 sec. The datum of the speed of acquisition of measuring data, besides the resolution, presents one of the most important in the choice of system and its wide application. The size of the scanning field is minimally 14x14mm, and optimally 25x14mm. The range of the scanning depths should be at least 10mm, and not bigger than 14mm. The scanner resolution should be at least ±25μm (40).

The most known representative of this method is Cerec system (Sirona Dental Systems GmbH; www.sirona.de) (41). This technique uses a number of light beams, in the shape of lines, projected on a preparation (linearly shaded surface). The beans in a quick oscillations move across the object so during a short period three-dimensional shape of preparation is made. Similarly to conventional photography, the camera at the point of shooting has to be hold as still as possible. The fixation of the camera opposite the object is not necessary at this system, because the time needed for data processing from all of 340 000 pixels is less then 0.5 sec. (picture 8). During 2005 two more oral scanners were presented: Evolution 4D and HintEls, but they are still not serially produced.

The problem of light reflection from the surface of hard dental substance has appeared at intra-oral optical scanner. That is overloading light-dark contrast of the projected linearly shaded surface. The solution to this probje nađeno u posipanju matirajućeg praška na skeniran zub. Loša strana celog tog sistema je u tome što se onda ne skenira zub nego površina nanetog sloja praška, pa ga zato treba što tanje naneti. Subgingivalno očitavanje se teško može sprovesti optičkim senzorima. Zbog toga stomatolog mora voditi računa da granice preparacije budu u vidljivom području.

lem was found in the sprinkling of mat powder onto the scanned tooth. The bad side of the problem is that, the tooth is not scanned then, but the cover of the sprinkled layer of powder, so it should be very thin. Sub gingival scanning is hardly to be done with optical sensors. So the dentist has to be careful for the boundaries of preparation to be in the visible area.



Slika 8. Šema preseka Cerec 2 glave skenera

Figure 8. Shema of Cerec 2 scaner

Ekstraoralni sistemi skeniranja sprovode se na modelu, pa iz tog razloga postoji potreba za zubotehničkom laboratorijom. Kod ovih sistema nije presudna visoka brzina sakupljanja podataka jer su i glava skenera i predmet koji se skenira nepokretni, već širina polja skeniranja i preciznost merenja.

Drugačije rešenje, za postizanje treće dimenzije pomoću CCD čipova, daje laserski triangulacioni postupak po Lelandais i Clainchard-u (1984). Ako se usmeri laserski tačkasti zrak sa oscilirajućim ogledalom za CCD kameru nastaće jedna jasna ograničena laserska linija. Ona se umesto linijski šrafirane površine takođe projektuje na preparaciju pod triangulacionim uglom. Analogno optičkoj triangulaciji, ovde je prisutan od visine zavistan dvodimenzionalni crtež preslikanog sloja laserskog svetla. Prednost je u većem kontrastu laserskog zraka nasuprot konvencionalnom izvoru svetlosti. Kako trigonometrijski proračun vertikalne dimenzije može biti obavljen samo duž preseka laserskog svetla, izvor laserskog zraka se mora, deo po deo, pomerati duž celog područja skeniranja. Potrebni utrošak vremena i neophodnost reprodukovanog pozicioniranja iziskuju fiksaciju senzora naspram objekta. Velika prednost ovih sistema je i mogućnost snimanja podminiranih površina. Ovaj način rada je za sada moguć samo kao ekstraoralna metoda.

Predstavnik tačkastog ekstraoralnog skenera je Cerec Scan (Sl. 9) ili Cerec inLab (Sl 10). Skener je fiksiran na jednom od motora mašine za frezovanje, a pokretan je predmet skeniranja. Rezolucija skenera je slična intraoraoralnom skeneru, ali je vreme skeniranja jednog zuba znatno duže. Za četvoročlani most potrebno je 2-3 minuta. Ove godine fabrika je razvila nov površinski skener visoke rezolucije, kod koga je ovo vreme svedeno na oko 40 sekundi (Cerec inEos) (42).

O brzini razvoja ekstraoralnih skenera slikovito govore podaci prve i druge generacije HintEls skenera. Greška

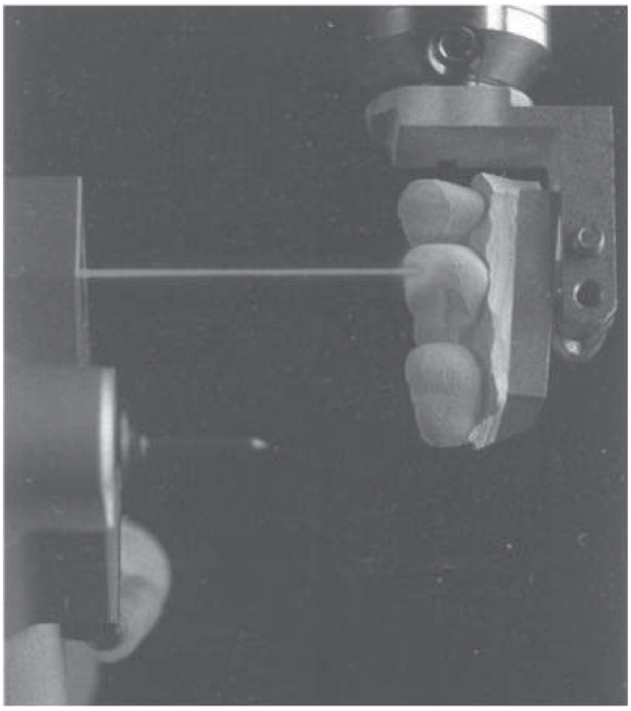
Extra-oral systems of scanning are done on a model, so there is a need for the dental technical laboratory. With this system there is not crucial the high speed of collecting the data, for the scanner head and the subject scanned are immovable, but the width of the scanned field and the measuring precision.

The different solution for attaining the third dimension with the help of CCD chips, gives the laser triangulation procedure according to Lelandais and Clainchard (1984). If the laser spotty bean is directed with oscillated mirror for CCD camera there will appear a clear limited line. It is, instead of linearly shaded surface, projected also to preparation under the triangular angle. In analogy to the optical triangulation, there is present, depending on height, two-dimensional drawing of copied layer of laser light .As trigonometry calculation of the vertical dimension can be done only along the cross section of laser light, the source of the laser beam has to be moved, part by part, along the whole scanning area. The time needed and the reproduction of the positioning needs the sensor fixation in front of the object. The great advantage of this system is the possibility of shooting undermined surfaces. This kind of work is, for now, only possible as extra-oral method.

The representative of extra-oral scanner is Cerec Scan (picture 9) and Cerec inLab (picture 10). The scanner is fixed on the one of the motors of the milling machine, and the scanning object is movable. The resolution of the scanner is similar to oral one, but the scanning time of a tooth is significantly longer. For the four parts bridge it is needed 2-3min. This year, the factory has developed a new scanner of the high resolution, where the time needed is shortened to 40sec. (Cerec inEos) (42).

About the speed of extra-oral scanner development speak the data of the first and the second-generation HintEls scanners. Scanning error of the extra-oral scanner is skeniranja ekstraoralnih skenera je 5 umesto 15 mikrona, rezolucija kamere je 1360 x 1030 pixel-a a bila je 512 x 512. Moguće je skenirati kompletan model (do 14 zuba), a brzina je 20 sekundi, u odnosu na 3 minute kod starog skenera.

now 5 instead of 15 microns; the resolution of the camera is 1360x1030 pixels instead of 512x512. It is possible to scan a complete model (to14 teeth), and the speed is 20 sec. instead of 3min with the old scanner.



Slika 9. Cerec Scan – integrisan laserski tačkasti skener na levom motoru
Figure 9. Cerec Scan - extra-oral laser scaner on left motors

Slika 10. Cerec inLab sistem - s leva na desno: inEos ekstraoralni skener, Cerec in Lab sa ugrađenim tačkastim skenerom, PC računar sa 3D softverom.
Figure 10. Cerec in lab system

Zaključci

"Idealan CAD/CAM sistem" već dugi niz godina predstavlja san mnogih istraživača. Obzirom da je preciznost nadoknada izrađenih CAD/CAM tehnologijom, u funkciji svih pojedinačnih grešaka postupaka i opreme a da je skeniranje početni izvor eventualnih nepreciznosti, veća rezolucija skenera će najznačajnije doprineti kvalitetu celokupnog sistema.

Direktno intraoralno skeniranje predstavlja najpoželjniju metodu, jer u sebi sadrži samo grešku metode i postupka skeniranja dok isključuje greške otiskivanja vilice i izrade modela.

Conclusions

The ideal CAD/CAM system is a dream of many researchers for many years. Considering that the precision of the reparation done with CAD/CAM technology, is in the function of the individual mistakes of actions and equipment, and the scanning is initial source of eventual imprecision, the better scanner resolution is going to contribute significantly to the quality of the system in the whole.

Direct intra-oral scanning presents the most desirable method, because it consists only method and scanning mistakes, and it excludes the mistakes of imprint and model making.

Intraoralnim skenerima se stalno povećava rezolucija, smanjuje vreme akvizicije podataka i poboljšava sistem merenje treće dimenzije. Postoje nagoveštaji o rešavanju problema refleksije svetlosti sa površine zuba, bez „matiranja“, čime će se značajno pojednostaviti postupak rada i povećati preciznost merenja. Razvijen je intraoralni skener koji je sastavni deo stomatološkog radnog mesta što omogućuje ili jednoseansni rad ili direktan prenos podataka u laboratoriju. Internet ili intranet komunikacija ordinacije i laboratorije će značajno približiti vreme izrade zubne nadoknade direktnim i indirektnim postukom.

Indirektno skeniranje otiska nije našlo široku praktičnu primenu. Indirektno skeniranje modela je, za sada, najčešće primenjivana metoda, pogotovo ako je potrebno skenirati veću površinu. Ekstraoralni skeneri, za razliku od intraoralnih, postaju robustniji, tako da se povećanjem pokretljivosti skenera omogućuje “otiskivanje” većih i podminiranih površina, koje su do skoro predstavljale jedan od glavnih problema optičkog skeniranja. „Otisak“ cele vilice postaje imperativ kod svih sistema. U tehničkom smislu, iz svih ovih razloga tačkasti laserski zrak polako gubi primat.

Intra-oral scanners is increasing in resolution constantly, decreasing the time of data acquisition and improving the system of the third dimension measuring. There are hints about the solution of the reflection of the light from the tooth surface problem, without “matting”, which will significantly simplify the working procedure and increase the measuring precision. Developed intra-oral scanner, which is an integral part of dentist working place, enables the one-séance work or direct transfer of the data into laboratory. Internet or intranet communication of the dental office and laboratory will significantly shorten the time needed for tooth reparation, with direct or indirect process.

Indirect scanning of the imprints has its wide practical application. Indirect scanning of the model has been the most often applied method, until now, especially if it was the larger surface. Extra-oral scanners, in contrast to intra-oral ones, became larger, so with the increase of the scanner mobility, it is possible to “imprint” larger and undermined surfaces, which, till recently, presented one of the main problems of optical scanning. The “imprint” of the total jaw is imperative for all the systems. Technically, those are the reasons why the spotty laser gradually looses its priority.

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