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A SYSTEM FOR MEASUREMENTS OF 3D SCANNED ORTHODONTIC STUDY MODELS

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Abstract: Plaster dental casts represent an important item in the process of diagnosis, therapy planning and documenting, both in orthodontics, as well as other areas of dentistry. Dental casts allow us to track occlusal contacts before the therapy as well as the changes during the growth and therapy. Although they do possess many positive features, due to the rapid advancements in technology, their negative sides have became more prominent leading to the more widespread use of digital 3D models as their replacement. In this paper, we present a web based system that allows us, after the casts have been scanned, to produce easily usable digital models, to store them and perform measurements on them. Performed measurements are suitable for futher processing and analysis.
Keywords: orthodontics, study models, digital 3D models, measurements.

1. INTRODUCTION

Orthodontic study models have a number of purposes and present necessary part of orthodontic documentation. In addition to clinical examination, intraoral and extraoral radiography images, study models present irreplaceable diagnostic means in orthodontic diagnostics. They are used to analyze irregularities of teeth and teeth groups, dental arches, jaw relations in three planes (sagital, transversal and vertical), which enables making of diagnosis, preparation of plan of orthodontic therapy and monitoring the course of treatment. Study models are used as a permanent document of condition of dentition development in desired time periods. Together with other orthodontic documentation, study models are used also for longitudinal observing of normal and abnormal development and growth of teeth and jaws. Study models have scientific-research significance because they serve also for publication and illustration of professional and scientific papers. In addition, they present important documents that have medical-legal significance for each patient and are kept for at least ten years [1].

By observing, measuring and evaluating the study models, we obtain the data necessary for the orthodontic therapy plan. Type of teeth, shape of teeth, assimetry of the teeth size, irregular arrangement of teeth, lack of space for regular position of teeth, position of the curve of Spee, interrelationship of tooth arches in occlusion as well as bite depth are determined by analysis of study models [1,2].

Although the plaster casts are the most precise ones, many difficulties exist when taking and casting dental impression, especially in persons with tooth irregularities such as narowness. By invention of impression mass such as alginate, these deficiencies have been avoided and almost ideal conditions have been created for taking impression and making of study models. Owing to the short time of binding of alginate mass, taking impression is eased also in younger patients. Impressions are taken by alginate mass, with the assistance of metal or plastic perforated spoons for upper and lower jaw. When mixing alginate, the instructions of the manufacturer should be obeyed, relating to the ratio of quantity of powder and liquid, temperature of the liquid and manner and speed of mixing. After taking impressions, a central or habitual occlusion is registered using the prepared wax patterns [3,4].

Plaster study models have a long and proven history in orthodontic diagnostics and therapy. They present so called golden standard with numerous advantages, such as: simple routine production in dental techniques, easiness of production as well as simple approach to the models for measurement of

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analysis necessary for making appropriate orthodontic diagnoses, owing to the possibility to put the study model in articulator and thus measure it in three dimensions [5].

Direct measurement on study models, besides the advantages, has also limiting factors such as: ideal placing of measuring instruments onto the models, the measurement itself on plaster study models requires a lot of time, and any accidental move by hand results in the error in results. Deficiencies in use of plaster study models are present in terms of storage, endurance and portability [6].

Three-dimensional models that authentically describe real objects, caused that mentioned technologies are used also in orthodontic practice. Digital models have numerous advantages, from simpler storage, through more efficient exchange of data to automation of certain processes. However, the question is posed whether such obtained models describe well enough the real study models on which orthodontic therapy is based. Except the stated problem, real obstacle for wider use in orthodontic diagnostics is also relatively high costs of quality three-dimensional scanners and related software necessary for quality work. Current trend in medical diagnostics is the use of accessible technologies that, supported by appropriate programs enable lowering of costs along with retaining of previously stated positive aspects of use of modern information technologies in medical practice.

For the complex analysis of structure of adhesives which are today used in orthodontics, it is best to use AFM (Atomic Force Microscopy), the procedure that allows analysis of structure at nano-level. The aforementioned technology determines properties of adhesives that are most frequently used in orthodontics, and especially those that achieve the highest bond strength oforthodontic brackets to tooth enamel - in clinical practice and establish correlation between the nanostructures of analyzed adhesives and bond strength of brackets bonded to the teeth [7,8].

Contemporary techniques enable scanning of impressions and their digitalization, which significantly eases the analyzing. Storage of digital models can be carried out on optical or some other media, which decreses the needs for space occupied by plaster study models. Digital photos and digital x-ray are already in use, therefore use of digital study models enables complete digitalization of diagnostic protocol [9].

In this paper, one such program is presented that enables the orthodont to make measurements of three-dimensional scanned study model in a simple and efficient manner, aimed at automated performance of orthodontic analysis.

2. METHODS OF 3D SCANNING

When we talk about methods of 3D scanning, basically we can divide them into two groups: contact and non-contact scanners. Since the use of contact scanners in orthodontics does not have significant differences in relation to traditional methods of measuring, in this paper we will pay attention to non-contact methods, first of all use of laser, structured light, and methods based on photogrammetry [10].

2.1. Use of laser for 3D scanning of objects

In use of laser for 3D scanning of objects, the most commonly used is one of the following methods: *time-of-flight*, triangulation and use of line lasers. *Time-of-flight* approach is based on the fact that the speed of light is final and that, on the basis of time necessary that the light crosses from the source till the object and receiver, it is possible to calculate the distance from the object to the source, ie. the receiver. By repeating this procedure for a number of points on the surface of the object, it is possible to reconstruct three-dimensional appearance of the object. However, due to the fact that the light crosses the distance of 1mm for approximately $3.3 \cdot 10^{-12}$ s, this method is more suitable for measuring larger distance at lower precision [11].

The method which is more favourable for scanning of smaller or closer objects is triangulation. This method is functioning in the following manner: laser light source projects a point onto the object, the camera records the position of the point and on the basis of the known distance between the camera and angle that it makes in relation to the laser source, it calculates the distance of the point to the camera. This process is repeated a required number of times until the conditions necessary for satisfactory reconstruction of three-dimensional object are fulfilled [10].

The deficiency of both mentioned approaches is in the fact that it is necessary to scan point by point which makes scanning in high resolution slow and expensive process. An important progress is achieved by the use of laser line sources that project a straight line onto the object, and on the basis of the appearance of deformed line, one can carry out the triangulation of large number of points in short period. This approach is illustrated in Figure 1. The problem of this approach is the need for rotating of object between each two recordings, where the final resolution depends on the number of steps, which is proportional to the time necessary for scanning [12].

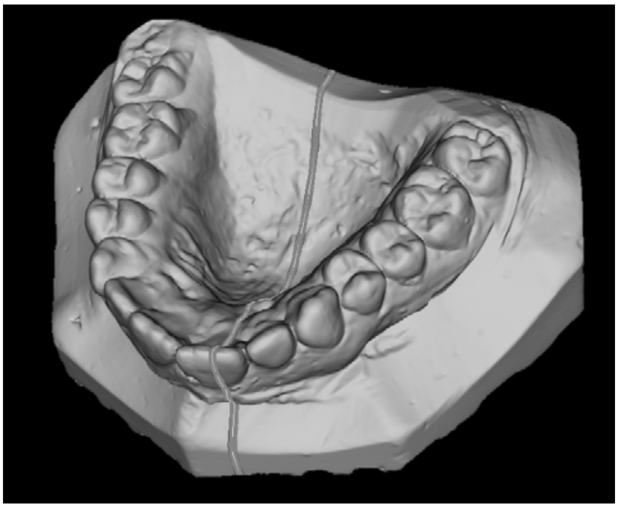

Figure 1. Line laser 3D scanner example

2.2 Structured light scanner

Structured light scanners operate in similar way as scanners with line laser, but instead of illumination of the object by one line, they carry out successive illumination of the object by predefined patterns (e.g. an array of lines, fields, etc.) and on the basis of that, they calculate partial three-dimensional surface of the object in one go, which largely speeds up the scanning process. Another advantage of this approach is possibility of decrease of certain errors of measurement, because the position of every point has been calculated several times through the use of various patterns of light. [13] The process of such scanning has been illustrated in the Figure 2.

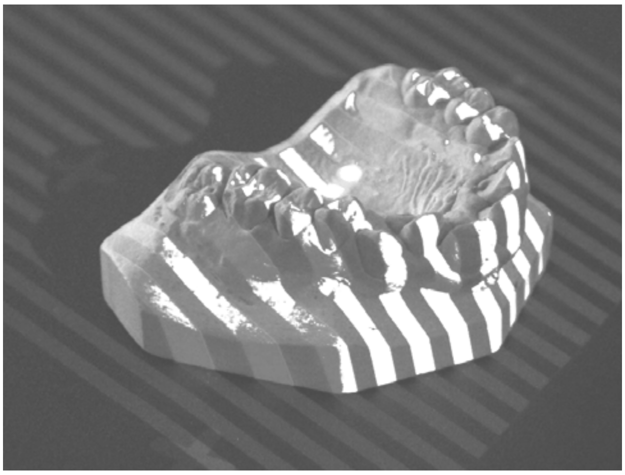

Figure 2. Structure light 3D scanner example

Problems with structured light scanner appear during scanning of objects that are extremely dark because the camera does not receive enough information for formation of the image, or the objects that are transparent or mirrorlike, because the camera does not see the object, but deformed image of its surroundings. These problems are typically solved by the use of special powder that is sprayed on the object before scanning, and is removed after the completion of the process.

Within this paper, industrial scanner with structured light has been used - Steinbichler (Zeiss) Comet L3D 5M [14]. Scanned object has been set on a robotized turntable that enables automation of the scanning process. This scanner uses a projector as a source of blue light and the sensor in the camera has 5 megapixel resolution. Since the system supports removable lenses on the projector and the camera as well, it is possible to select desired maximal resolution depending on the size of scanned object, as shown in the Table 1.

Table 1. Steinbichler Comet L3D 5M dimensions of object and scanning resolutions

Dimensions of the object W x H x D [mm]	Resolution in [μm]
74 x 62 x 45	30
260 x 215 x 140	100
480 x 400 x 250	190

2.3. Scanning based on photogrametry

Due to the developments of performances of computer systems, systems based on photogrammetric reconstruction of three-dimensional objects have become more popular [13]. These systems calculate relative positions of the camera for each recording on the basis of a large number of photos of the same object made from different angles. After that, they determine and match key points on related photographs, and on the basis of that, they calculate the position in 3D space of every single detected point. This process is extremely demanding from the point of view of computer resources, both processing and operational memory, but no specialized equipment is needed except a digital camera of appropriate resolution and quality. As a solution, we get a model that, in addition to the information about the shape of the object also contains the data about the colour of each reconstructed point – a texture. The basic weakness of this process is much slower and complicated process of both acquisition of photos and reconstruction of objects, impossibility of scanning of objects without sufficient number of surface features (e.g. smooth balls and similar uniform shapes), and impossibility of scanning of very dark, transparent or mirrorlike objects. The special problem is non-existance of reference scale of reconstructed object. Namely, if it is necessary to carry out measurements in real world units, there must exist a reference within the scan based on which the scaling of the size of the reconstructed object can be carried out, which additionally complicates the work with these systems. The example of photogrametric scanned object is given in the Figure 3.

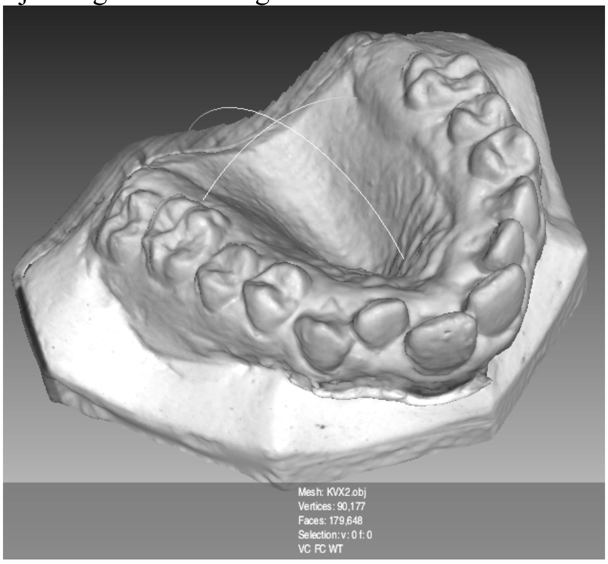

Figure 3. Example of photogrammetric reconstruction

2.4. Intraoral scanners

Intraoral scanners are specialized devices that enable generating 3D models without previous taking casts and making study model. In the work, they use previously described methods with positioning of the source of light and cameras on the top of the probe that carries out scanning. Depending on selected technology, they may generate one-colour models or models with full use of colours and textures. Although the researches have shown existence of statistically significant differences, the conclusion of the author is that clinically significant differences for observed parameters have not been recorded [15].

3. PROGRAM OrthoPhoto4D

Program package OrthoPhoto4D (OP4D) has been created with the aim to ease the process of measuring of digital models to the orthodonts. Basic charateristic of this system is that it is web based and that the installation of a special software in the computer of orthodont is not necessary, except one of the contemporary programs for access to web (Google Chrome, Mozilla Firefox, Apple Safari and similar). Having this in mind, it is possible to use the program from the mobile or tablet devices with the remark that such approach is not suitable for making precise measurements because there is a significant difference in accuracy when selecting the points by use of pointers and touch screen. The program enables muti-user work, where each user has isolated copies of data not accessible to other users. The work with digital models in PLY (Polygon File Format / Stanford Triangle Format) [16] and NXS (Nexus) [17] formats has been supported.

3.1. Process of program use

The first step in practical use of the system is entering the data about the models in the system, which can be accomplished in two manners. The first manner includes uploading of the 3D model file to the web application server to be stored there. In this way, the future access from other devices is possible, as well as the isolation of data between the users.

The second manner implies that digital representations of objects are already present at some external server that is configured to enable the access from this web application (CORS settings [18]). This way makes it possible to use the program also for measuring of the models for which the users do not want to be under direct control of the program for any reason (confidentiality of data, use of intranet server, shared access from several different programs, etc.).

User interface for objects management has been presented in the Figure 4.

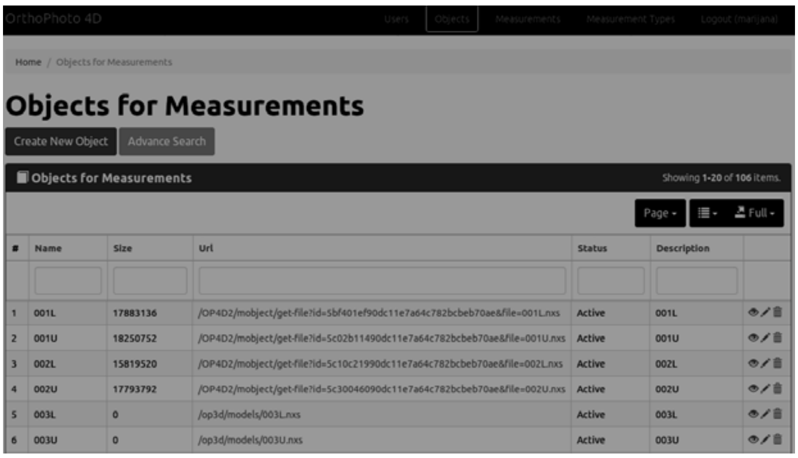

Figure 4. OP4D – Management of objects for measurement

The process of measurement itself includes selecting the object which we will measure, as well as desired type of measurements to be made. The system has been made in a way that it is possible to carry out arbitrary number of measurements on each object, regardless of whether they are of the same kind or different kinds. Performance of different types of measurements enables that several measure analysis are carried out on the same model, while multiple measurements of the same kind enable future processing of the results, whether in the form of averaging of obtained values (eg. if the measurements are performed by the same user) or analysis of measurements performed by different operators. Process of selection has been shown in the figure 5.

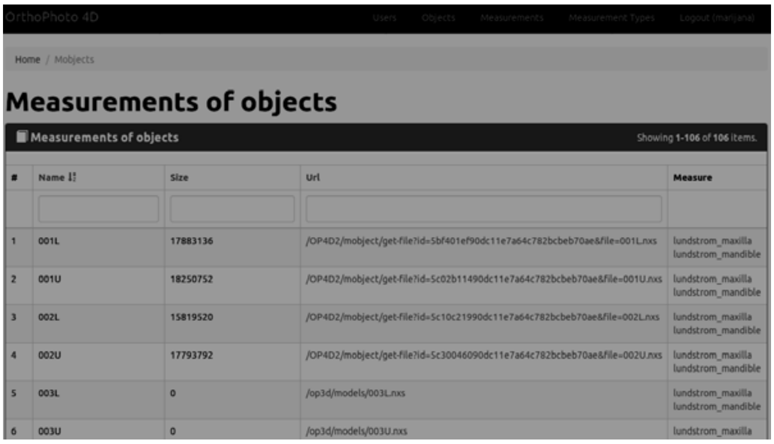

Figure 5. OP4D – Selection of objects and types of measurements

The basic part of the application is the subsystem for measurements. It is based on the use of 3DHOP [17] system and uses SpiderGL [19] library for screen display. As previously mentioned, the system supports PLY and NXS formats. The basic difference is in the fact that PLY objects are loaded in one step which means that the user has to wait for the model to be entirely loaded before any display is possible. Having in mind that size of files that present 3D objects can be significant, it is obvious that this can present a problem in practical work in case of inadequate internet connection to the server. NXS format enables accomodation of more versions of the same model into the same file. These versions present qualitative successive iterations of the model starting from a very rough model that is possible to be shown to the user very qucikly, till the model of full resolution that contains the data identical to the source model.

User interface, shown in the Figure 6, has been divided into three basic parts:

1. Toolbar for 3D display management

It enables return to the initial position, increase and decrease of the display of the object, moving of light source in the scene, tools for independent measuring of distance, tools for display of cross-section of the object, and increase of the display on the full screen.

2. Display of 3D object
3. Bar with measuring values

It has been generated on the basis of selected type of measurement and enables the user to select the value for measurement, to display previously performed measurement, and to record measured values or to give up measuring.

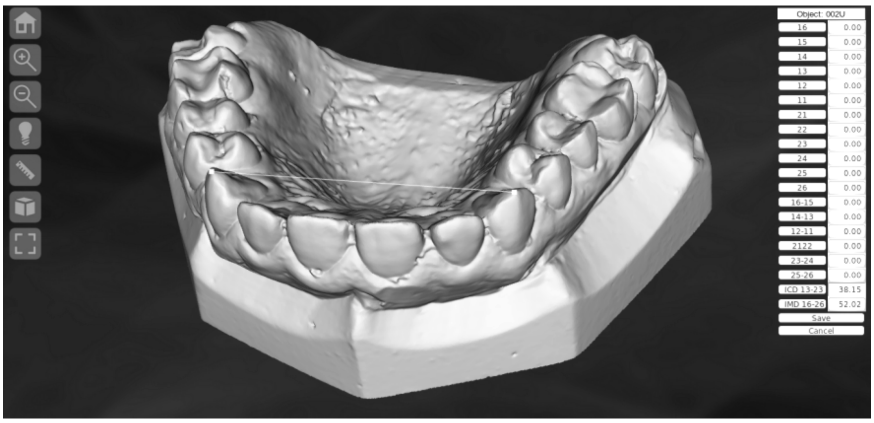

Figure 6. OP4D – User interface for measuring objects

After the model has been measured, the measurements are kept in the data base and are coded using the JSON format [20]. This format enables large flexibility because it has dynamic structure and supports presentation of data in the form of, inter alia, scalars, vectors, maps and other hierarchically organized structures. For the needs of the program, besides generic data about the model, the data are stored about each measured size that include measured distance as well as the position of points in the ends of measured distance. Such way of storage and presenting of data enables simple use in other programs for advanced analysis or integration with other sources of data. Example of the data format has been given in the figure 7.


```
{
...
  "icd_33_43_value": "25.58",
  "icd_33_43_points": [
    [
      1.0379058414909,
      5.4615013326765,
      -25.00786183337
    ],
    [
      26.06280884612,
      8.0032579755712,
      -20.376421373367
    ]
  ],
  "imd_36_46_value": "44.47",
  "imd_36_46_points": [
    [
      32.458396711901,
      12.533109766887,
      0.60714785591602
    ],
    [
      -11.616495083141,
      10.496214089123,
      -4.9822254892519
    ]
  ]
}
```


Figure 7. Example of data in JSON format

3.2. Comparison of measured values with the program Meshlab

Mehslab [21] is an advanced program package, developed by ISTI-CNR [22] research center, intended for processing of three-dimensional meshes and models, and offers to the users possibilites to preview, change, shade and measure three-dimensional objects. It supports a wide variety of file formats, such as: PLY, STL, OFF, OBJ, 3DS, VRML 2.0, U3D, X3D and COLLADA.

For the needs of control of precision of measurements in OP4D program, a trial measurement has been carried out of inter-canine distance on 30 scanned study models of mandible in Meshlab and OP4D environment, and statistical analysis of obtained results has been performed.

Measurements performed by use of OP4D program had the mean value of 25,47 mm with the variance 4,41 mm and standard deviation 2,10 mm, while the measurements performed by Meshlab program had the mean value of 25,56 mm, variance 4,43 mm and standard deviation 2,11 mm. Variance of difference between measurements is 0,02 mm, and deviation is 0,15 mm. Pearson correlation is 0,997, while the value p for the paired T-test is less than 0,005. These results have been shown in the table Table 2.

Table 2. Display of statistical analysis results

	OP4D	Meshlab
Mean value [mm]	25,47	25,56
Standard deviation [mm]	2,10	2,11
Variance [mm]	4,41	4,43
Standard deviation of difference [mm]	0,15	
Variance of difference [mm]	0,02	
P	0,003	
Pearson correlation	0,997	

Similar analysis of precision of two different 3D scanners (Atos Optical Scanner and Lazak Scan Laboratory Scanner) concluded that measurement differences of between 0.017mm and 1.109mm are acceptable in use in orthodontics [23].

Mentioned data strongly suggest that two compared methods of measurement in practical use give the results where no significantly important difference has been recorded, and having in mind obtained values, there is no clinically significant difference in results. Since the program package Meshlab presents one of the most used packages of that sort in the market, and is being used in the wide scope of purposes, obtained results may be observed as a validation of correct work of OP4D program for stated purposes.

4. CONCLUSION

Use of digitalized study models enables easy and efficient storage, as well as simple access to and analysis of digital data. Problem of long-term storage od models and avoiding their damage has been largely simplified or eliminated. This paper gives the overview of the most frequently used technologies of 3D scanning of objects with special emphasis to the structured light scanners which were used in the practial part of the paper. By use of appropriate program packages, such as OP4D, a simple work with digital models has been enabled, whether from the personal computer or from a mobile device. Developed software enables defining of arbitrary set of measurements, with the possibility of multiple measuring of the model, whether from the same or different operators. Obtained values can be presented in a simple and open format appropriate for data exchange. Statistical analysis has shown that the measurements carried out in this program are acceptable alternative to the conventional methods of measurements.

5. ACKNOWLEDGEMENT

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6. REFERENCES

[1] N. Jakšić, I. Šćepan, B. Glišić, *Ortodontska dijagnostika*. Beograd, 2004.

[2] M. Marković i saradnici, *Ortodoncija*, Beograd, Ortodontska sekcija Srbije,; 1982.

[3] T. Tanić, J. Milić J. Radojičič, *Uvod u osnovne principe dijagnostike i terapije u ortopediji vilica*, Pančevo, 2009.

[4] E. Nakaš, A. Tiro, V. Džemidžić, L. Redžepagić-Vražalica, M. Ajanović, *Osnovi ortodontske dijagnostike*, Sarajevo, Stomatološki fakultet sa klinikama, 2014.

[5] B. Rheude, P. L. Sadowsky, A. Ferriera, A. Jacobson, *An Evaluation of the Use of Digital Study Models in Orthodontic Diagnosis and Treatment Planning*, The Angle Orthodontist, Vol. 75−3 (2005) 300−304.

[6] O. Zilberman, J. A. V. Huggare, K. A. Parikakis, *Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models*. Angle Orthodontics, Vol. 73 (2003) 301–306.

[7] V. Mirjanić, Dj. Mirjanić, *AFM testing of nanostructure of resilience orthodontic bonding solutions orthodontic adhesive*, Contemporary Materials, Vol. VII−1 (2016) 51−59.

[8] V. Mirjanić, Dj. Mirjanić, *AFM analysis of enamel damage due to etching with orthophosphoric acid*, Contemporary Materials, Vol. VII−1 (2016) 60−72.

[9]D. Demirović, *Osnovi fiksne tehnike u ortodonciji*, Sarajevo: Stomatološki fakultet Sarajevo, 2005.

[10] R. Szeliski, *Computer Vision: Algorithms and Applications*, Springer, 2010, 577−613.

[11] L. Dongming, P. Yunhe, *Digital Preservation for Heritages: Technologies and Applications*, Springer Science & Business Media, 2011, 12−18.

[12] Ch.W. Sensen, B. Hallgrimsson, *Advanced Imaging in Biology and Medicine: Technology, Software Environments, Applications*, Springer Science & Business Media, 2008, 86−94.

[13] F. Bernardini, H. Rushmeier, *The 3D model acquisition pipeline*, Computer graphics forum 2002, Vol. 21−2 (2002) 149−172.

[14] *COMET L3D – Compact 3D Sensor*, http://optotechnik.zeiss.com/en/products/3d-scanning/comet-l3d

[15] S. B. Patzelt, A. Emmanouilidi, S. Stampf, J. R. Strub, W. Att, *Accuracy of full-arch scans using intraoral scanners*, Clinical oral investigations, Vol. 18−6 (2014) 1687−1694.

[16] P. Bourke, *PLY - Polygon File Format,* http://paulbourke.net/dataformats/ply/

[17] M. Potenziani, M. Callieri, M. Dellepiane, M. Corsini, F. Ponchio, R. Scopigno, *3DHOP: 3D Heritage Online Presenter*, Computers & Graphics, Vol. 52 (2015) 129−141.

[18] Cross-Origin Resource Sharing (CORS) - HTTP | MDN, *https://developer.mozilla.org/en-US/docs/Web/HTTP/CORS*

[19] M. Di Benedetto, F. Ponchio, F. Ganovelli, R. Scopigno, *SpiderGL: A JavaScript 3D Graphics Library for Next-Generation WWW*, Proceedings of the 15th International Conference on Web 3D Technology, ACM (2010) 165−174.

[20] D. Crockford, *The application/json media type for javascript object notation (json)*, https://tools.ietf.org/html/rfc4627

[21] *Meshlab*, http://www.meshlab.net

[22] *Istituto di Scienza e Tecnologie dell'Informazione*, http://www.isti.cnr.it

[23] N. Majstorović, L. Čerče, D. Kramar, M. Soković, B. Glišić, V. Majstorović, S. Živković, *Examination of Scanner Precision by Analysing Orthodontic Parameters*, Balkan Journal of Dental Medicine, BaSS, Vol. 21−1 (2017) 32−43.

СИСТЕМ ЗА МЈЕРЕЊА 3Д СКЕНИРАНИХ СТУДИЈСКИХ МОДЕЛА
У ОРТОПЕДИЈИ ВИЛИЦА

Сажетак: Гипсани студијски модели представљају важно средство у процесу дијагностике, планирања терапије и документовања, како у ортопедији вилица, тако и у другим областима стоматологије. Студијским моделима пратимо оклузалне односе прије почетка лијечења, али и промјене током раста и терапије. И поред њихових бројних квалитета, усљед развоја технологије су у први план избили њихови недостаци, што је довело до све значајније употребе дигиталних тродимензионалних модела као њихове замјене. У овом раду је приказан веб базирани систем који по обављеном скенирању модела омогућава једноставно генерисање употребљивих дигиталних модела, те складиштење и вршење мјерења на тако добијеним моделима. Мјерења извршена на овај начин погодна су за даљу обраду и извођење анализа.

Кључне ријечи: ортопедија вилица, студијски модели, дигитални тродимензионални модели, мјерења.