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PAPERS

Unexpected corneal reflection phenomenon alters smartphone 3D image-based models of the eye

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Reconstruction of a 3D eye model by photogrammetry from a smartphone video could be prospectively used in self-diagnosis, screening and telemedicine monitoring of diseases of the front part of the eye and its surroundings. The main use could be found in the treatment of diseases of the curvature and surface of the cornea and in follow-up after some refractive procedures. In our work, we create 3D image-based models of the eye after scanning the face with a smartphone. An unexpected phenomenon appeared during the reconstruction of the transparent cornea – a crater-like depression was formed at the place where nearby objects reflected on the cornea, which corresponds to the first Purkinje image, the so-called glint. We thus encountered complications that may arise when modelling transparent living structures from a video taken in a normal environment, which will need to be solved if we want to create such 3D models of the eye using this method for medical purposes. Another 3D reconstruction approach or additional algorithms must be considered as a future work.

Keywords: 3D image-based modelling, eye model, photogrammetry, keratoconus, corneal reflections, transparent cornea, glint

1 Introduction

The use of mobile phones as disease-screening devices is promising [1]. Screening of anterior segment eye diseases by mobile phones from a direct photo of the eye has been successfully used in conjunctivitis [2], keratitis [3, 4], dry eye disease [5], pterygium, a disease of the degenerated conjunctiva which overgrows on the cornea [6-8], and in keratoconus, with progressive thinning of the cone-shaped cornea [9]. A photograph of the eye can show the front part of the eye in detail, but since it is two-dimensional, it does not allow to display the depth. The 3D model of the eye offers the third dimension, even if it does not allow to observe the deep structures in the same way as a standard examination of the anterior segment of the eye using a slit lamp.

3D models of organs or parts of the human body are helpful in various medical specializations and other research fields. Created with the help of a smartphone, they are presented during the reconstruction of the whole head [10], face [11], foot [12], analysis of the cranial deformation [13], and in dental monitoring [14].

Creation of a 3D model of the eye could be helpful in the diagnosis of diseases of the front part of the eye and its surroundings. It would be possible to notice many pathological changes around the eye and on its surface, for example, inflammations or pathological formations. We would see the greatest perspective in the screening of diseases of the corneal curvature – keratoconus and pellucid marginal degeneration. Keratoconus is a common disease of the cornea, it occurs in one out of 2000 cases, and it progresses most in young patients and causes deterioration of vision. If diagnosed and managed by an ophthalmologist early, one can help the patient to improve and stabilize vision. Less common is pellucid marginal degeneration, it is also most often diagnosed in people between 20-40 years of age due to the deterioration of vision due to the protrusion of the cornea above the place of its thinning [15]. A 3D representation of the cornea could also be helpful in self-monitoring or telemedical monitoring of patients after some refractive and corneal surgeries.

We have analysed several technologies that allow to obtain a 3D model by a smartphone.

TrueDepth is a technology used by Apple that projects more than 30,000 invisible points onto a nearby object and, thanks to their reflection, can model a three-dimensional object. It uses the iPhone's front camera and its main function is facial recognition [16]. The technology is smart enough to adapt to changes in the appearance, such as makeup, glasses, facial hair, and

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hats, and is available from iPhone 12 Pro. To use it, it is necessary to use an application that supports this technology [17]. Thurzo *et al.* point to the biggest differences between the 3D TrueDepth scan of the face and the Cone beam computer tomography scan (CBCT scan) in the area around the eye [18]. Due to the need to install the application and the documented lower model quality in the eye area, we do not include this technology in our experiments.

Light detection and ranging (LiDAR) is an optical technology capable of creating models of three-dimensional objects. It is often used, for example, in the development of autonomous vehicles to determine distances between the vehicle and other objects. LiDAR emits laser beams of infrared light most often with a wavelength of 905 nm or 1550 nm into its surroundings which are subsequently reflected back from objects to the sensor [19, 20]. Although the LiDAR technology is described in the literature as eye-safe and classified as "Class 1 eye-safe (IEC 60825-1:2014) standard", nowhere in the literature did we find the use of a LiDAR scanner for direct close-up eye research. To the best of our knowledge, the safety of such close-up and long-term eye scanning has not yet been proven. In addition, according to the authors, who scanned the Lego blocks using various methods to obtain 3D models, the LiDAR was unable to scan a small Lego block due to insufficient generated grid resolution [17]. It also requires the installation of an application for its use [17]. Because of the mentioned factors, we do not approach this 3D modelling method either.

Photogrammetry uses methods of recording, measuring and interpreting information about 3D objects from photographic images [21]. On the basis of photogrammetry, 3D image-based model is created based on the photos taken from different angles [22]. Computer vision focuses on detecting, grouping, and extracting features (edges, faces, etc.) present in a given image and then trying to interpret them as three-dimensional traces. Currently, there are various software tools available on the market that require users to take several photos from different angles with a regular camera or mobile phone. Then the software can automatically generate corresponding 3D models of the given photographed object based on these photos [23]. Samosir and Riyadi claim that the data obtained from the smartphone camera is of the comparable quality as that of digital single-lens reflex cameras (DSLR cameras) and can be used as their alternative in photogrammetry [24]. Moreover, it was implemented in medicine as a non-invasive approach for obtaining 3D digital scans of intraoral and extraoral structures to design and fabricate individualized appliances for children with craniofacial disorders or various dental specializations [25].

The aim of our work was to create a 3D model of the eye using photogrammetry from a video captured by a smartphone to contribute to smartphone screening and diagnostics in ophthalmology. The use of a smartphone for this purpose was chosen for its availability and ease of use. We chose photogrammetry as an approach to 3D model reconstruction for its safety, high resolution and the possibility of recording video on any mobile device.

In the next sections, we describe the method we used to reconstruct our 3D eye models using a smartphone, the analysis of the models, and what difficulties we encountered while analysing them.

2 Methods

2.1 Capturing the video

The scheme of the method is depicted in Fig. 1. We decided to use smartphone video to obtain images to create a 3D model of the eye. In total, we performed 10 experiments with different settings and compared four of them with visually highest quality. The video contains a large number of image frames which were shot as 30 frames per second (fps). From four compared models, three models were acquired in horizontal direction (thus from the beginning of one ear around the nose to the other ear), but the 4th model was acquired vertically (from the eyebrow to the lower part of the lower eyelid), since we wanted to more accurately shot the area of the eye gently covered by the upper eyelash (Table 1). With the help of various software it is possible to extract these frames from video in defined available time interval. The videos were shot on the iPhone 13 PRO smartphone, the resolution of the videos was 4K, *ie* 3840×2160 px. iPhone 13 PRO contains A15 Bionic chip, 6-core CPU, 5-core GPU, and 16-core Neural Engine. The phone has a 12MP system and 3 cameras, 6× optical zoom range and possibility to shoot 4K video at 24 fps, 25 fps, 30 fps, or 60 fps.

The photographed subjects were motionless, the videos were also stable without the need for a stabilization device. When creating a video, large differences in the position of the captured object which could occur when shooting with a regular camera are mostly eliminated. The images thus seamlessly connect to each other. It was not possible to estimate or determine in advance how long it would take to shoot individual videos.

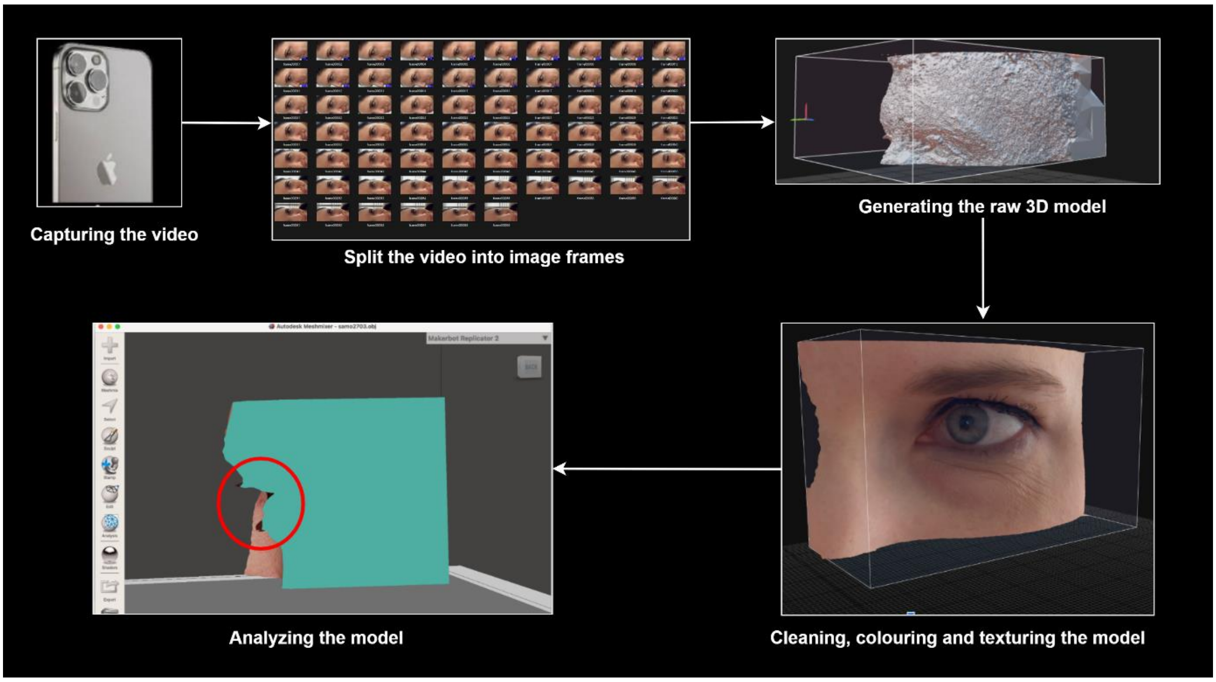

Fig. 1. Scheme of the method of creating a 3D eye model employing 3D image-based modelling using a smartphone video

Table 1. Four models and their selected parameters

Model number	1	2	3	4
Capturing direction	Horizontal	Horizontal	Horizontal	Vertical
Video length (s)	8	9	8	6
Number of all image frames	240	270	240	180
Frame retrieval	Every 6th	Every	Every 3rd	Every 3rd
Number of used image frames for modelling	40	270	80	60

2.2 Splitting the video into the image frames

After getting the video, the single frames were extracted in various intervals to create the image dataset using the RealityCapture program [26]. The resolution of image frames was 3840×2160 px. As part of experiments, we used different splitting intervals to cut the video into frames. In Table 1 we present 4 selected combinations of parameters, according to which we managed to build three-dimensional models.

Most of the models used video captured in normal daylight, we tried to add lighting with a continuous flash light from a mobile phone without any change in model quality. Model No. 1 was reconstructed from every 6^{th} image as a first attempt to be not computationally difficult, but its quality was insufficient. To obtain model at higher quality, Model No. 2 was reconstructed from a larger number of images – from every image frame extracted from video. The reconstruction process took linearly more time. Then we created Model No. 3 as a compromise between the two mentioned models according to the image frame retrieval. In this model, every 3^{rd} frame was used.

2.3 Generating the 3D model

To create our 3D models, we used the RealityCapture [26] computer program, permitted for academic use. It is photogrammetric software developed by Capturing Reality, designed to create 3D models from photos or laser scans. The software generates accurate triangular meshes of diverse objects from buildings to people, accepts an unlimited number of source images, and can use multiple available CPU and GPU cores to process the data. The software has low hardware requirements. The 3D model was created using an Nvidia GTX 1060 graphics card and an AMD Ryzen 3600 processor which we considered as a minimal configuration from the point of view of computational complexity. The first step after loading the photos into RealityCapture is the registration of the images. It is a process that calculates the positions of photos and their orientations- that means that the algorithm checks whether there were any variations of the camera position during the shooting and tries to re-align the images for their continuity. Next, we choose the area we want to reconstruct. We limited the reconstruction to an appropriate area, in our case the area of the eye. This procedure will speed up the calculation of the model because unimportant parts of the scene will not be considered at all. After modelling the raw model, we will further preprocess the image which includes cleaning, colouring and adding a texture.

2.4 Analysis of the 3D model

We performed the analysis of the 3D model in the free 3D modelling software MeshMixer [27], developed by Autodesk. The model was analysed in horizontal and vertical sections of the eye to discover the corneal curvature and surface. First, the vertical section was cut in a vertical plane which runs through the central of the pupil, and horizontal section created by horizontal plane running through the centre of the pupil and perpendicular to the vertical section plane. These sections were performed manually by the observer.

3 Results

In total, we performed 10 experiments with different settings, from which we present four representing 3D models and compare them visually (Fig. 2). The 1st and 2nd models have a lumpy surface with no evident curvature of the cornea at all. We have analysed in detail 3rd and 4th model in MeshMixer software [27] because of their highest quality to obtain data about the surface and curvature of the cornea. Both models were of comparable visual quality.

Fig. 2. Four 3D models of the eye according to Tab. 1.

The aim of the experiment was to analyse the shape and curvature of the eye surface in the horizontal and vertical plane and provide a better understanding of its geometry and properties. If we obtained several points on the surface of the cornea, we would be able to calculate the inscribed circle to these points and thus determine the curvature of the cornea (Fig. 3). We observed the curvature in the horizontal and vertical section of the eye, the presence of elevations and depressions. Due to the higher quality of the models, we expected the cornea to be convexly curved on the model, as on the real eye. When observed from the side, however, a cornea with a broken course was displayed – there was a depression like a crater. We analysed these findings using horizontal and vertical sections according to section line draw in the schematic eye in the right bottom corner of sub-images in Fig. 4.

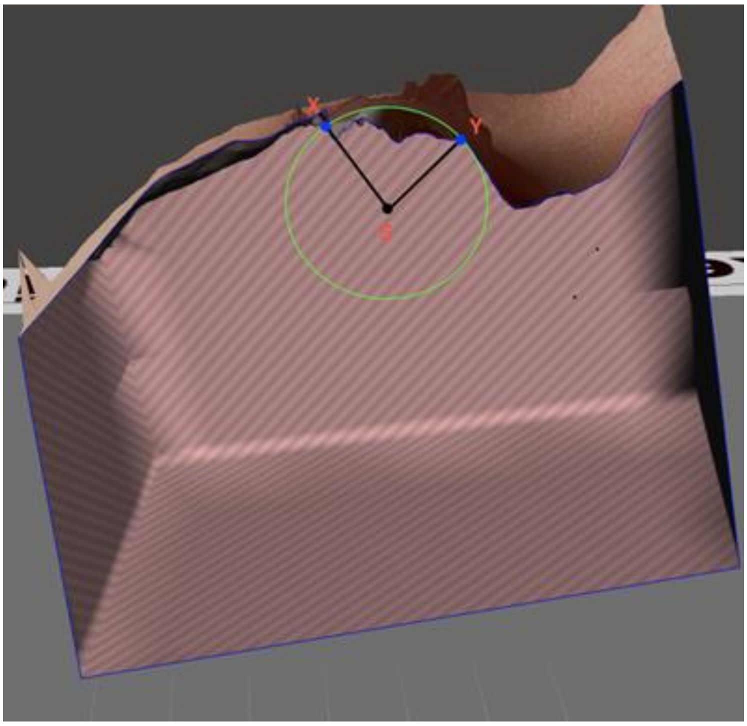

Fig. 3. The principle of inscribing a circle to points on the surface of the cornea in order to determine the curvature of the cornea

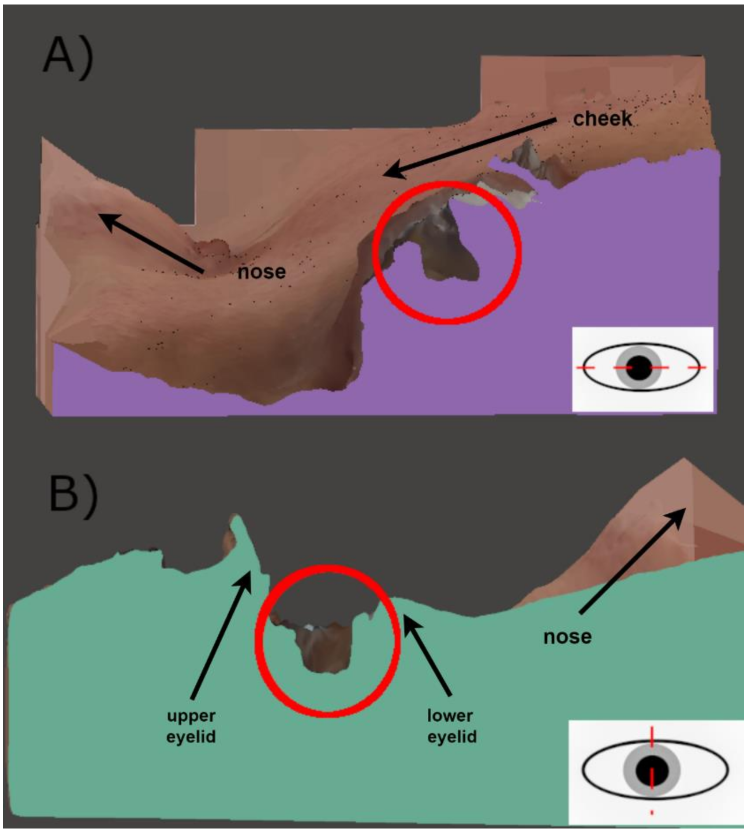

Fig. 4. Eye sections in model No. 3. with schematic eye in the right bottom corner showing the direction of the section line. A) Horizontal section, B) vertical section. A crater-like depression is marked in a red circle on both sections.

Therefore, we analysed the individual images from which the models were reconstructed and found the reflections of the surrounding objects on the transparent cornea of the eye in the extracted image frames precisely in the location of the depression in the 3D model. In the 3D model, the depression was like a crater, which we initially consider to be a malfunction during modelling or an artifact.

When photographing a subject in daylight near a window in order to improve lighting conditions and thus better video quality, we observed the reflection of a building visible in the distance behind the window (Fig. 5). This phenomenon is the reflection of an object on the outer surface of the cornea, it is also called Purkinje image number 1, the so-called glint. Purkinje images were described by the Czech anatomist and physiologist Jan Evangelista Purkinje in the 19^{th} century. He observed a candle 30 cm away from the eye and its reflection in the transparent structures of the eye. Four reflections were described, namely the first on the outer surface of the cornea, the second on its inner side, the third on the outer side of the lens and the fourth on its inner side [28].

Fig. 5. Reflection of a building visible through a window on the cornea of a subject shot near the window from the front and in profile

4 Discussion

We explored reconstructing a 3D eye model using a smartphone video.

There were unexpected complications with the smartphone 3D eye modelling – the cornea does not appear as it is naturally curved but contains a crater-shaped depression, which makes any further medical analysis impossible. This phenomenon appeared during the reconstruction of the transparent cornea and was formed at the place where nearby objects reflected on the cornea. The cornea is a relatively small structure, which requires high accuracy in modelling. However, it has one more property that is probably problematic in modelling and that is its transparency. Modelling a transparent structure can be difficult, the camera may not be able to accurately capture the surface and edges of such structures, surrounding objects may be reflected on it, which cannot be avoided during normal user imaging in non-experimental conditions. Problems with 3D modelling of transparent objects using photogrammetry are also described by Surmen [22]. He recommends covering the modelled surfaces of such objects with matting spray or powder, but this is not possible to use on the eye.

In our models, the cause of the depression is the corneal reflection of nearby objects, the so-called first Purkinje image, which will disturb the modelling and the program will create a hole in the place of this reflection. This observation could be different using another smartphone 3D modelling approach, which would certainly be the goal of our future work. We could also focus on creating an algorithm that would be able to model the expected curvature at the point of corneal reflection according to the surrounding curvature of the cornea without reflection. This reflection was undesirable in our case and it was very problematic to record a video with minimal corneal reflection and still sufficient quality. We assume that shooting a video without any corneal reflection would be almost impossible for a standard user in home conditions. On the other hand, this reflection has been successfully used as part of eye-tracking systems where its occurrence and location are highly desirable [29].

Another application of 3D eye modelling could be person identification. Even though the 3D upper face models we have created seem accurate enough to the observer, we do not know if observed corneal reflections will not affect the identification algorithms.

Examination of the curvature and surface of the cornea of the proposed 3D eye models after resolving described 3D modelling complications, could help us to detect corneal diseases such as keratoconus, pellucid marginal degeneration and complications after some refractive surgeries. However, the creation of 3D eye models that we are researching is not currently applicable for this purpose.

We chose mobile phone scanning for its availability and simplicity. A common target group for the screening of these operations are young adults, who are very close to the use of mobile phones. Creating a video of their eye is a matter of seconds for them and could reveal diseases whose management could contribute to improving the vision and vision prognosis of these patients.

Further research is needed in this area. Another reconstruction approach or additional algorithms incorporated in the 3D modelling tools must be considered as future work. In the future, we anticipate the use of other 3D reconstruction methods that we will be able to apply to the eye. As mobile phones evolve, TrueDepth technology is likely to become more accurate in the ocular area. It is also possible that we will routinely use LiDAR in ocular area, which we have not yet dared to use in this region.

5 Conclusion

3D image-based models of the eye from smartphone video were reconstructed to be used in screening of corneal curvature and surface diseases. The emergence of an unexpected phenomenon during the reconstruction of the model occurred, thus made these models impossible to be used in ophthalmologic diagnostic process. When modelling the cornea, a crater-like depression was created at the point of reflection of surrounding objects on a transparent corneal structure that corresponds to the first Purkinje image. It points to the complications that can arise when modelling transparent living structures in a normal environment, which will need to be resolved if we want to use such model for medical analysis in ophthalmology.

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References

[1] J. C. Moses, S. Adibi, N. Wickramasinghe, L. Nguyen, M. Angelova, and S. M. S. Islam, "Smartphone as a Disease Screening Tool: A Systematic Review," *Sensors*, vol. 22, no. 10, Art. no. 10, Jan. 2022, doi: 10.3390/s22103787.

[2] P. Mukherjee, I. Bhattacharyya, M. Mullick, R. Kumar, N. D. Roy, and M. Mahmud, "iConDet: An Intelligent Portable Healthcare App for the Detection of Conjunctivitis," in *Applied Intelligence and Informatics*, M. Mahmud, M. S. Kaiser, N. Kasabov, K. Iftekharuddin, and N. Zhong, Eds., in Communications in Computer and Information Science. Cham: Springer International Publishing, 2021, pp. 29-42, doi: 10.1007/978-3-030-82269-9_3.

[3] Z. Li *et al.*, "Preventing corneal blindness caused by keratitis using artificial intelligence," *Nat Commun*, vol. 12, no. 1, Art. no. 1, Jun. 2021, doi: 10.1038/s41467-021-24116-6.

[4] L. Wang *et al.*, "Feasibility assessment of infectious keratitis depicted on slit-lamp and smartphone photographs using deep learning," *International Journal of Medical Informatics*, vol. 155, p. 104583, Nov. 2021, doi: 10.1016/j.ijmedinf.2021.104583.

[5] Y. Hong and M. Hasegawa, "Study of minor dry-eye detection using smartphone camera based on deep learning," in *International Workshop on Advanced Imaging Technology (IWAIT) 2021*, SPIE, Mar. 2021, pp. 621-626, doi: 10.1117/12.2590408.

[6] S. R. Abdani, M. A. Zulkifley, and A. M. Moubark, "Pterygium Tissues Segmentation using Densely Connected DeepLab," in *2020 IEEE 10th Symposium on Computer Applications & Industrial Electronics (ISCAIE)*, Apr. 2020, pp. 229-232, doi: 10.1109/ISCAIE47305.2020.9108822.

[7] S. R. Abdani, M. A. Zulkifley, and N. H. Zulkifley, "Group and Shuffle Convolutional Neural Networks with Pyramid Pooling Module for Automated Pterygium Segmentation," *Diagnostics*, vol. 11, no. 6, Art. no. 6, Jun. 2021, doi: 10.3390/diagnostics11061104.

[8] M. A. Zulkifley, S. R. Abdani, and N. H. Zulkifley, "Pterygium-Net: a deep learning approach to pterygium detection and localization," *Multimed Tools Appl*, vol. 78, no. 24, pp. 34563-34584, Dec. 2019, doi: 10.1007/s11042-019-08130-x.

[9] W. M. D. W. Zaki, M. M. Daud, A. H. Saad, A. Hussain, and H. A. Mutalib, "Towards Auto-mated Keratoconus Screening Approach using Lateral Segment Photographed Images," in *2020 IEEE-EMBS Conference on Biomedical Engineering and Sciences (IECBES)*, Mar. 2021, pp. 466-471, doi: 10.1109/IECBES48179.2021.9398781.

[10] D. Matuzevičius and A. Serackis, "Three-Dimensional Human Head Reconstruction Using Smartphone-Based Close-Range Video Photo-grammetry," *Applied Sciences*, vol. 12, no. 1, Art. no. 1, Jan. 2022, doi: 10.3390/app12010229.

[11] R. Raghavendra, K. B. Raja, A. Pflug, B. Yang, and C. Busch, "3D face reconstruction and multimodal person identification from video captured using smartphone camera," in *2013 IEEE International Conference on Technologies for Homeland Security (HST)*, Nov. 2013, pp. 552-557, doi: 10.1109/THS.2013.6699063.

[12] K. Hu, Y. Zhong, and G. Wu, "Reconstruction of 3D Foot Model from Video Captured Using Smartphone Camera," *JFBI*, vol. 8, no. 3, pp. 493-500, Jun. 2015, doi: 10.3993/jfbim00145.

[13] J. L. Lerma, I. Barbero-García, Á. Marqués-Mateu, and P. Miranda, "Smartphone-based video for 3D modelling: Application to infant's cranial deformation analysis," *Measurement*, vol. 116, pp. 299-306, Feb. 2018, doi: 10.1016/j.measurement.2017.11.019.

[14] R. S. Morris *et al.*, "Accuracy of Dental Monitoring 3D digital dental models using photograph and video mode," *Am J Orthod Dentofacial Orthop*, vol. 156, no. 3, pp. 420-428, Sep. 2019, doi: 10.1016/j.ajodo.2019.02.014.

[15] A. A. of Ophthalmology, *2022-2023 BCSC Section 8: External Disease and Cornea Print*. American Academy of Ophthalmology, 2022.

[16] A. Breitbarth, T. Schardt, C. Kind, J. Brinkmann, P.-G. Dittrich, and G. Notni, "Measurement accu-racy and dependence on external influences of the iPhone X TrueDepth sensor," in *Photonics and Education in Measurement Science 2019*, SPIE, Sep. 2019, pp. 27-33. doi: 10.1117/12.2530544.

[17] M. Vogt, A. Rips, and C. Emmelmann, "Compa-rison of iPad Pro®'s LiDAR and TrueDepth Capabilities with an Industrial 3D Scanning Solution," *Technologies*, vol. 9, no. 2, Art. no. 2, Jun. 2021, doi: 10.3390/technologies9020025.

[18] A. Thurzo *et al.*, "Smartphone-Based Facial Scan-ning as a Viable Tool for Facially Driven Ortho-dontics?," *Sensors*, vol. 22, no. 20, Art. no. 20, Jan. 2022, doi: 10.3390/s22207752.

[19] S. Royo and M. Ballesta-Garcia, "An Overview of Lidar Imaging Systems for Autonomous Vehicles," *Applied Sciences*, vol. 9, no. 19, Art. no. 19, Jan. 2019, doi: 10.3390/app9194093.

[20] B. Song *et al.*, "Smartphone-Based LiDAR Appli-cation for Easy and Accurate Wound Size Measure-ment," *Journal of Clinical Medicine*, vol. 12, no. 18, Art. no. 18, Jan. 2023, doi: 10.3390/jcm12186042.

[21] E. M. Mikhail, "Introduction to Modern Photogrammetry (WSE) / Najlacnejšie knihy." Accessed: Oct. 28, 2023. [Online]. Available: https://www.najlacnejsie-knihy.sk/kniha/introduction-to-modern-photogrammetry.html?gclid=Cj0KCQjw4vKpBhCZARIsAOKHoWTvVXJ78uMzh4PRbAIsO0GCgi2w12JadOhIqVtVBKgeolqW5CckN1kaAlNNEALw_wcB

[22] H. K. Surmen, "Photogrammetry for 3D Reconstruction of Objects: Effects of Geometry, Texture and Photographing," *Image Analysis and Stereology*, vol. 42, no. 2, Art. no. 2, Jul. 2023, doi: 10.5566/ias.2887.

[23] "Best photogrammetry software in 2023: The ultimate guide," Sculpteo. Accessed: Oct. 28, 2023. [Online]. https://www.sculpteo.com/en/3d-learning-hub/3d-printing-software/photogrammetry-software/

[24] F. Samosir and S. Riyadi, "Comparison of Smart-phone and DSLR Use in Photogrammetry," in *International Conference on Aesthetics and the Sciences of Art*, Bandung, Indonesia: Bandung Institute of Technology, 2020, doi: 10.51555/338620.

[25] A. Thurzo, W. Urbanová, I. Neuschlová, D. Paouris, and M. Čverha, "Use of optical scanning and 3D printing to fabricate customized appliances for patients with craniofacial disorders," *Sminars in Orthodontics*, vol. 2, no. 28, pp. 92-99, Jun. 2022, doi: 10.1053/j.sodo.2022.10.005.

[26] C. Epic Games, "RealityCapture - 3D Models from Photos and/or Laser Scans." Accessed: Nov. 09, 2023. [Online]. https://www.capturingreality.com/

[27] Autodesk, "Meshmixer." Accessed: Nov. 09, 2023. [Online]. Available: https://meshmixer.com/

[28] O. J. Grüsser, "J. E. Purkyně's contributions to the physiology of the visual, the vestibular and the oculomotor systems," *Hum Neurobiol*, vol. 3, no. 3, pp. 129-144, 1984.

[29] I. E. Haddioui, "Learner Behaviour Analysis through Eye Tracking," 2012, Accessed: Oct. 29, 2023. [Online]. https://www.academia.edu/81178959/Learner_Behaviour_Analysis_through_Eye_Tracking

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