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Introducing the FIDENTIS 3D Face Database

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Abstract: Face databases have assumed an important role in a variety of clinical and applied research domains. However, the number of datasets accessible to the scientific community is limited and the knowledge of their existence may be concealed from a wider range of specialists. In the present paper we introduce a sizeable dataset of 3D facial scans – FIDENTIS 3D Face Database (F3D-FD or FIDENTIS Database), which is accompanied by basic demographic and descriptive data. The database is structured according to recorded subjects, and comprises single-scan entries as well as a smaller number of multi-scan entries. The multi-scan entries vary in the time passed between recording sessions and in the devices employed to collect the 3D data. The total number of 2476 individuals puts our database within the category of large-scale databases. The 3D scans are accessible through a web-based interface at www.fidentis.cz. A licensed version of the database is available to interested parties upon signing a license agreement. Because of its varied composition, and low target-specificity the database has capacity to be of great assistance for the worldwide research community.

Key words: face database; face processing; reference datasets; European population

Introduction

During the last two decades, three-dimensional recording has emerged as a progressive documentation technique, beneficial for a daily routine workflow in a variety of scientific fields, such as forensic sciences (Urbanová et al. 2015; Urbanová et al. 2017), human osteology (Ege et al. 2004, Jurda and Urbanová 2016), clinical research (Šrubař et al. 2015), the entertainment and game industry (Chalás et al. 2017), and the humanities (Demetrescu 2015). Photo-realistic textured surface scans of the human body – acquired by technologies ranging from laser or white light scanning to passive photogrammetry to infra-red sensors – have reached a quality that allows multiple tasks (such as measurement, diagnostics, archiving, data management, and quality control)

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to be carried out accurately and without the need for direct interaction with a living subject (Rosati et al. 2010). In comparison to traditional techniques, most notably 2D digital photography, 3D imagery has the advantage of including information about the depth of objects. This allows relative independence in establishing illumination and points of view. Similarly, it avoids the need for creating three-dimensional illusions in order to achieve an appearance comparable to physical reality. This is essential for carrying out assessments (visual or metrical) which are analogical to those conducted in real world scenarios.

Three-dimensional models have been particularly beneficial for studies of facial morphology, as human faces are more frequent subjects of scientific research than other parts of the body. For its informative, functional and esthetical values, facial geometry has been considered essential in establishing a person's identity in criminal investigations (Jain et al. 2000; Urbanová 2016; Gupta et al. 2010), as well as in commercial biometric systems (Bowyer et al. 2006). In addition, it has been crucial to assess pre- and post-operative status in orthodontics (Rosati et al. 2010) and craniofacial surgery (Maal et al. 2008, Kau et al. 2006). Facial geometry also has been a subject of multiple perception studies in psychology (Atabaki et al. 2015) and the entertainment industry (Chalás et al. 2017, Ferková et al. 2017). The majority of these applications are dependent on reference datasets mapping inter- or intra-population variation, including entries controlled for external conditions (e.g., expression, head position, occlusion, illumination etc.) (Yoshino et al. 2002, Zhang and Gao 2009), or entries collected over an extended period of time (Ricanek et al. 2006). Each discipline, however, puts different requirements on the collected datasets. Clinical fields are more interested in tracking the progress of particular patients, or in establishing population reference standards in order to improve efficacy of treatment management (Šrubař et al. 2015). In contrast, experts focusing on producing automated face algorithms are more interested in factor-controlled datasets, such as databanks simulating facial expressions or human emotions (Yin et al. 2006), apparent facial similarities (twins studies) (Vijayan et al. 2011), disguises (sun-glasses, hoods, caps) or make-up (Colombo et al. 2011), because these factors are known to interfere with face processing (Yoshino et al. 2002).

Building a 3D face database is a time-consuming and source-demanding task. Since many researchers lack appropriate resources to collect sizeable datasets, they are dependent on broadly available databases. The first face databases available to the scientific community were composed of two dimensional images, such as photographs, video recordings or videosequences, e.g., (Phillips et al. 1998; Sim et al. 2002; Erdem et al. 2015), many of which remain accessible despite having been created in the 1990s, e.g., (Samaria and Harter 1994). As the technology evolved, sets of 3D facial scans acquired by a variety of recording modalities (for example, facial scanners, structured light scanners, single camera photogrammetry-based algorithms, IR sensors, and dynamic face capturing systems) have been gradually collected and made public (Kusumoputro and Satria 2003; Fanelli et al. 2011; Yin et al. 2008).

Regardless of their initial purpose or technical specifications, the currently available 3D databases differ in three main ways: the total number of recorded subjects, the total number of 3D images (textured scans, meshes, and cloudpoints), and the resolution (geometry and texture) at which the 3D imagery appears in the database. While some databases focus on collecting human faces of different subjects (in these cases, more is considered better), others collect fewer subjects, but with multiple records per individual, preferably recorded under different conditions.

A list of 3D face databanks currently available for various scientific purposes has been compiled by Krishna et al. (2013). An additional summary of existing datasets has been provided by Calistra (2015). According to these overviews, none of the accessible datasets contains more than 1,000 individual subjects. The largest existing public 3D face database is the ND2006 Face Database. This dataset, collected at the University of Notre Dame, contains over 13,000 scans from approximately 900 individuals. The institution is extremely active in providing a variety of biometric datasets. Of the available datasets, 3D face data are also included in the 3D Twins Expression Challenge (3D-TEC) Data Set, Face Recognition Grand Challenge (FRGC v.2.0) data collection, and Series D, F, and J2 of the ND-Collection.

Additionally, the Texas 3D Face Recognition Database and the Bosphorus Database rank among the most widely applied datasets. Intended as facial expression databases, both sets include a large number of scans but fewer individuals. The former contains 118 adults, while the latter includes 105 individuals. Additional 3D face databases include the BJUT 3D database, the 3D_RMA Database, the Basel Face Model 2017, the Binghamton University 3D Facial Expression Database (BU3DFE), the Extended m2VTS Database, the University of Milano Biccoca 3D face database (UMB) and PhotoFace. These datasets comprise between 100 to 453 subjects.

It is evident that most of the available face databases fall within the category of technically oriented datasets and that the research community lacks a generic 3D face database mapping a sizeable portion of a given population. In the present paper, we introduce the FIDENTIS 3D Face Database, which intends to fill this vacancy and offers exciting new prospects for 3D face processing.

Database specifications

The project which led to the creation of the database started in early 2012 under the auspices of the FIDENTIS research group at Masaryk University, Czech Republic. FIDENTIS is a collaboration among experts from various scientific fields (anthropology, biostatistics, and computer sciences) aimed at developing guidelines for comparing human faces. Since then, a small dataset has expanded into a legitimate 3D face database. In this form the project was approved by the Research Ethics Committee at Masaryk University.

Participants

To date, 3D face scans from 2,476 participants have been collected and listed in the database. The majority of the individuals in the database are Czech citizens. Following local legislation, the age of 18 demarcates adulthood from childhood. Adult participants have originated mostly from cohorts of undergraduate and post-graduate students enrolled at the authors' home university (Masaryk University, Brno, Czech Republic). Sub-adult participants have been added courtesy of several local elementary schools. Prior to being scanned, all adult participants are asked to sign an informed consent form. On behalf of minors, informed consents are signed by their parents or legal guardians.

Data acquisition

Data acquisition follows a standardized lab protocol. The scanning is conducted indoors under controlled lighting conditions, mostly at the facilities of the Laboratory of Morphology and Forensic Anthropology, Department of Anthropology, Faculty of Science, Masaryk University (Brno, Czech Republic). The exception is a portion of sub-adult individuals who are scanned at cooperating local schools. In these cases, the lighting control is restricted to avoidance of direct sunlight.

The participants are captured with one of three Vectra scanners. Primarily used is the Vectra M1 (Canfield Scientific, Inc, Fairfield, NJ), a stereo-photogrammetric-based optical scanner. Vectra M1 is a facial imaging system capable of capturing the geometry and high-quality texture (12 Mpx) of a human face. In addition, the Vectra XT device, a half-body imaging system (Canfield Scientific, Inc, Fairfield. NJ) is employed. For the purposes of the face database, the system is set to the face scanning mode exclusively. The third scanner employed is Vectra H1. It is a handheld scanner accessorized with a large built-in lens, and resembles a professional digital camera in both appearance and control.

The pre-scanning phase is identical for all three Vectra devices. All participants are asked to take off their glasses, earrings, or other accessories. Locks of hair covering the face or falling over ears are either pulled back with a plastic headband or hair clips or brushed back behind ears. During the Vectra M1-based data acquisition, participants are seated on a revolving stool, and asked to maintain a natural head position and neutral facial expression with eyes open. Vectra M1 is a double camera system with a limited narrow range (100°) that cannot capture the entire face at once. If only a single frontal scan is taken, lateral parts of the face and ears are not measured properly, generating distorted surface geometry and blurry surface texture. To avoid these disturbances, each face is captured in three head positions: a frontal view, and left and right semi-profiles (rotation in app. 30°). For scanning with Vectra XT device, participants stand still while ear-to-ear facial morphology is captured in one scan. The system consists of three pods fixed on a floor stand adjustable for individual heights. For short individuals (for instance children 4 years old or younger), the lift with the scanning pads fails to reach the level of the child's face even if slid to the lowest position. These participants are scanned standing or squatting on a height-adjustable stool. Ultimately, the image acquisition executed by Vectra H1 resembles the one by Vectra M1; a limited range prevents the lenses from capturing a face all at once. Therefore, three partial scans are acquired while a person is standing upright.

Post-processing

The images captured by all three scanners are processed in Mirror® Medical Imaging Software. The program accommodates necessary steps in image processing in a user-friendly fashion. The scans are manually cropped to eliminate unwanted background and noise. For Vectra XT, raw scans often include the neck and upper body parts which are cut from the final scans, but no additional adjustment is carried out. Vectra M1 and H1 scans, in contrast, require extensive post-processing in order to acquire complete face models. Once raw scanning noise and technically unsuitable parts are cut out, semi-lateral scans are aligned approximately with the frontal model to complement the face using a 3-point alignment algorithm. The automatic "register mesh" function is then run to match corresponding surfaces. While Vectra H1 scans are processed directly in Mirror® Medical Imaging Software, in which aligned scans are stitched into high resolution textured meshes using software functionalities, Vectra M1 scans are processed in MeshLab, v1.3.3, an open source application for mesh processing (Fink et al. 2007), in which the three models are merged into a single mesh using the Poisson surface reconstruction filter. The filter parameters are set to preserve the highest level of details of the model (Octree Depth set to 12, Solver Divide to 10, Sample per node and Surface offsetting both set to 1).

Final adjustments for any type of meshes are carried out using the GOM Inspect software, where the meshes are checked for errors ("Eliminate Mesh Errors" function) and holes ("Close Holes – Automatically" function). A textured model is generated by adding the original texture onto the adjusted model.

Each facial scan is translated and rotated to fit the standardized position according to the Frankfurt horizontal, with the origin of the Cartesian coordinate system placed at the tip of the nose (i.e., pronasale landmark). For the purpose of the database, the Frankfurt horizontal is defined by the points left/right tragion and left palpebra inferior (all according to the definitions in Table 1).

Database structure

The database is structured by subjects and contains 3D datasets as follows (see also Fig. 1):

1. Raw edited models are partial 3D scans from the frontal and two semi-lateral views cropped manually of background and additional noise, including distorted

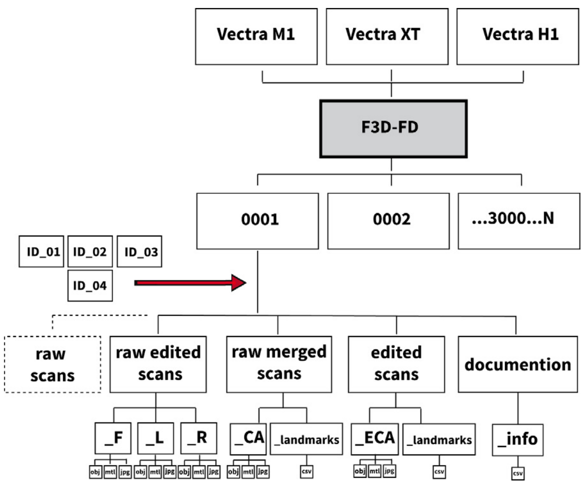

Fig. 1. The structure of the FIDENTIS 3D Face Database

Table 1. Definitions of anthropometric landmarks identified on 3D facial images in this study

Orbital region	1	Exocanthion (ex) right	The point at the outer commissure of the eye where the outer margin of the upper eyelid meets the lower eyelid. If the exact position cannot be located, the point is in the intersection of imaginary lines obtained by prolonging the eyelid margins.	EX_R
	2	Exocanthion (ex) left		EX_L
	3	Endocanthion (en) right	The point at the inner commissure of the eye, where the inner margin of the upper eyelid meets the lower eyelid. It is the most medial point at the lacrimal caruncle. If a skin fold is present (epicanthus, plica mongolica, plica marginalis fetis) and the point is not visible, the landmark is defined as the point where the fold crosses the lower eyelid.	EN_R
	4	Endocanthion (en) left		EN_L
	5	Palpebra superior (pas) right	The point is located at the intersection of a line passing through the eye center (parallel to the mid-sagittal plane) and the caudal (lower) margin of the upper eyelid.	PAS_R
	6	Palpebra superior (pas) left		PAS_L
	7	Palpebra inferior (pai) right	The point located at the intersection of a line passing through the eye center (parallel to the mid-sagittal plane) and the upper margin of the lower eyelid.	PAI_R
	8	Palpebra inferior (pai) left		PAI_L
Nasal region	9	Glabella (g)	The outermost midline point between the eyebrows.	G
	10	Subnasale (sn)	The lowest posterior midline point at the angle formed by the outline of nasal septum and upper lip.	SN
	11	Alare (al) right	The most lateral anterior point of the wing of the nose.	AL_R
	12	Alare (al) left		AL_L
	13	Nasion (n)	The point in the midline on the nasal root, the deepest point of the nasal root.	N
	14	Pronasale (prn)	The most anterior midline point of the nasal tip with the head positioned in the Frankfurt horizontal plane. If the nasal tip is bifid the point is located in the mid-sagittal plane between the elevations.	PRN

Labial region	15	Labrale superius (ls)	The midpoint of the upper vermilion line. In case of the bow-shaped upper vermilion the point is located in the mid-distance between the cheilion points.	LS
	16	Stomion (sto)	The point located at the intersection of the closed mouth fissure and the midline. If the mouth is open the point is localized at the lower margin of the upper lip.	STO
	17	Labrale inferius (li)	The most anterior midline point at the lower margin of lower vermilion.	LI
	18	Cheilion (ch) right	The point located at the labial commissure.	CH_R
	19	Cheilion (ch) left		CH_L
	20	Crista philtri (cp) right	The point located at the place, where the line running through the superior margins of the upper vermilion, meets the inferior margin of the crista philtri.	CP_R
	21	Crista philtri (cp) left		CP_L
	22	Sublabiale (sl)	The midpoint of the mentolabial sulcus. The point is located at the flexion point of the concavity.	SL
Mandibular region and outer part of the face	23	Gnathion (gn)	The most anterior inferior point located in the midline at the lower margin of the mandible.	GN
	24	Gonion I (goI) right	The lateral inferior point located at the mandibular angle.	GOL_R
	25	Gonion I (goI) left		GOL_L
	26	Zygion II (zy) right	The most lateral point of the face located on the horizontal line running through the eye centers. From the lateral view the point is located at the extension to the posterior eyebrow margin (alternatively, at the eyebrow margin).	ZY_R
	27	Zygion II (zy) left		ZY_L
	28	Pogonion (pg)	The most anterior midline point located at the chin with the head positioned according to the Frankfurt horizontal plane.	PG

Auricular region	29	Tragion (t) right	The point located at the upper margin of the tragus in the little notch where the cartilage is attached to the head if positioned according to the Frankfurt horizontal place.	T_R
	30	Tragion (t) left		T_L
	31	Superaurale (sa) right	The most superior point located at the upper margin of the auricle with the head positioned according to the Frankfurt horizontal plane.	SA_R
	32	Superaurale (sa) left		SA_L
	33	Subaurale (sba) right	The most inferior point located at the lower margin of the earlobe with the head positioned according to the Frankfurt horizontal plane. If the "attached earlobe" appearance is present the point is identical to the otobasion inferius point.	SBA_R
	34	Subaurale (sba) left		SBA_L
	35	Postaurale (pa) right	The most posterior point of the posterior margin of the auricle with the head positioned according to the Frankfurt horizontal plane.	PA_R
	36	Postaurale (pa) left		PA_L
	37	Otobasion superius (obs) right	The point where the upper margin of the auricle attaches to the head.	OBS_R
	38	Otobasion superius (obs) left		OBS_L
	39	Otobasion inferius (obi) right	The point where the earlobe attaches to the cheek skin (lower attachment).	OBI_R
	40	Otobasion inferius (obi) left		OBI_L
	41	Praeaurale (pra) right	The point at the intersection of the line between the otobasion superius and otobasion inferius points, at the level of the postaurale point.	PRA_R
	42	Praeaurale (pra) left		PRA_L

polygons or texture imperfections (available for Vectra M1 and Vectra H1 only, 3 partial models per face model are included) (Fig. 2a). Labeling: ID_L, ID_R, ID_F for left semi-lateral, right semi-lateral and frontal scans in that order.

2. Raw merged models include one-piece face scans (with ears), as created from the partial scans by the merging procedure (Vectra M1), or they are direct outcomes of the raw image data post-processing (Vectra XT, Vectra H1); posterior parts of the models have been trimmed; the scans have been edited for polygon overlapping, cleaned and translated to the origin of the coordinate system (placed at tip of the nose) (Fig. 2b). Labeling: ID_CA.

3. Edited models are uniformly trimmed models that encompass frontal ear-less parts of the face (available for Vectra M1, H1 and XT) (Fig. 2c). Labeling: ID_ECA.

Note that a set of raw models (original unedited scans) that include the technical noise and unwanted background are not included in the database.

4. Landmarks are sets of 42 landmarks collected for each scan in the "raw merged" category (Fig. 2d). The data acquisition was conducted according to definitions as stated in Table 1. For each 3D model, the landmark dataset is available in csv format. Labeling: ID_landmarks.

5. Associated documentation is a list of specifications attached to a 3D model and featuring information regarding sex (male or female), date of birth, date of scan (both formatted to YYYY/MM/DD), age (the participant's exact age is computed by subtracting the date of birth from the date of data acquisition), birth place (city, country), residence (city and country) nationality, residence, highest achieved level of education, recording device, and presence of facial make-up. Labeling: ID_info.

Technical specifications

All 3D models included in the database are principally available in "obj" format. The texture is presented in the "jpg" format with a resolution of 12Mpx and 96 dpi. The number of vertices is variable and dependent on the acquisition device. For M1 scans, it counts 60 thousand vertices, while for XT models it is approximately 20 000 vertices. There is also a slight discoloring of the XT-related texture in comparison to the brighter texture recorded by the Vectra M1 device (Fig. 3).

The set of landmarks is presented in the "csv" format which contains landmark labels, values of X, Y, Z-coordinates, and the status for a given mesh (enabled/disabled). For instance, EX_R x refers to the X-coordinate of the right exocanthion. The data are presented in the same order as are the definitions of landmarks in Table 1.

Demographic profile of the database

Currently, the database contains 2476 individuals, of whom 1305 are adults and 1171 are subadults. The sample consists of 1322 females and 1154 males. The age distribution is highly skewed towards younger individuals. The majority of adults (66%) are aged less than 25 years. The sub-adult participants range from 3 to 17 years of age, of which 79% fall within the range of 7 to 12 years.

Seventy-five percent of the adults and 97% of the children are of Czech nationality, while Slovak citizens make up 20% of the adults. Other nationalities are represented by a small number of individuals. Twenty-two individuals of Czech or dual Czech nationality were born abroad,

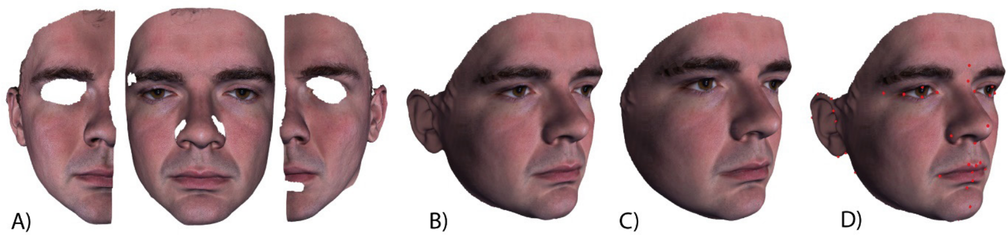

Fig. 2. Sample data as included into the FIDENTIS Database. A) Partial 3D scans from the frontal and two semi-lateral views labeled as "raw edited models", B) one-piece face scans with lateral parts including ears, labeled as "raw merged models", C) uniformly trimmed ear-less models, labeled as "edited models", D) a set of landmarks collected for each subject as displayed on a corresponding 3D face model

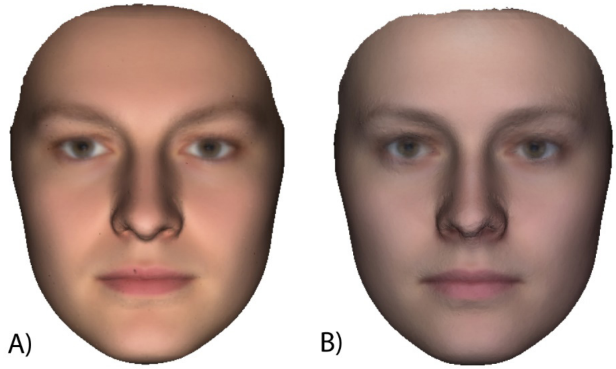

Fig. 3. Texture-present average 3D faces computed from the data as computed by the Vectra M1 (A) and Vectra XT (B) devices

of whom 8 marked their place of birth as the Slovak Republic.

Single-scan database entries

Adults

Of 1305 adults currently included in the database, 689 are females and 616 are males. The average age is 27.39 years – 26.69 years for females, and 28.17 years for males (with statistically significant differences, M-W U test, p=0.02). The oldest individual currently listed in the database is 83 years old. Additional demographic characteristics are listed in Tables 2 to 4.

Individuals aged between 20 and 29 comprise the majority of the dataset. Females comprise a larger portion of the database across all age groups, except for among the participants aged between 30 and 39, and among those in the consecutive age group (40-49 years). The overall sex-related distribution among age groups, however, is balanced (χ^2=10.36, p = 0.11).

Nearly 47% of adult individuals reported "secondary education (high school graduation)" as the highest level of education achieved. 20% are college graduates (bachelor's degree), and 21% received a master's degree. The remaining percentage contains participants of either a lower (primary) or higher (doctoral) levels of education (Table 4).

There are sex-related inconsistencies in the achieved level of education category (χ^2=20.15, p= 0.005). Whereas the lower levels of education (primary) and college graduates are skewed female, the categories related to the certification/training in professions, often associated with technically-oriented fields, are male-inclined. Surprisingly, similar male-inclined results were shown for the category of the highest level of education (doctoral degree).

Sub-adults

Of 1171 children and adolescents currently listed in the database, 633 are female, while 538 are male. The average age is 10.8 years—10.9 years in females, and 10.7 years in males (statistically significant sex-related age differences,

Table 2. Distribution of nationalities for the subjects included into the FIDENTIS Database nationalities

Nationality	Adults		Sub-adults	
	n	%	n	%
Czech	973	74.56	1135	96.93
Slovak	255	19.54	9	0.77
Russian	9	0.69	1	0.09
Polish	8	0.61		
Ukrainian	8	0.61	4	0.34
Spanish	7	0.54		
Hungarian	4	0.31		
Italian	4	0.31		
Croatian	2	0.15		
French	2	0.15	1	0.09
Greek	3	0.23	1	0.09
Israeli	3	0.23		
Maltese	2	0.15		
Portuguese	2	0.15		
Serbian	3	0.23		
Turkish	2	0.15	1	0.09
Armenian	1	0.08	1	0.09
Belarusian	1	0.08		
Belgian	1	0.08		
Bosnian	1	0.08		
Brazilian	1	0.08		
British	1	0.08		
Dutch	1	0.08		
Estonian	1	0.08		
German	1	0.08	1	0.09
Kazakhstani	1	0.08		
Lithuanian	1	0.08		
Syrian	1	0.08		
Tatarian	1	0.08		
Vietnamese	1	0.08	3	0.26
Serbo-Croatian			1	0.09
Romanian			2	0.17
Dual Czech/?*	2	0.15	11	0.94
Missing data	2	0.15		
Total	1305	100	1171	100

* refers to dual Czech and American, British, Canadian, Greek, Italian, Austrian, Slovak, Dutch, or Serbian nationalities

Table 3. Age-related distribution for adult subjects included into the FIDENTIS Database

Age category (years)	Total		Females		Males	
	n	%	n	%	n	%
18-19	148	11.34	88	12.77	60	9.74
20-29	887	67.97	471	68.36	416	67.53
30-39	128	9.81	63	9.14	65	10.55
40-49	77	5.90	38	5.52	39	6.33
50-59	48	3.68	25	3.63	23	3.73
>=60	14	1.07	4	0.58	10	1.62
Missing data	3	0.23	0	0.00	3	0.49
Total	1305	100	689	100	616	100

Table 4. Distribution of the level of achieved education for the adult subjects included into the FIDENTIS Database

Achieved level of education	Total		Females		Males	
	n	%	n	%	n	%
Primary	95	7.28	58	8.42	37	6.01
Secondary (high school graduation)	444	34.02	247	35.85	197	31.98
Secondary (certified in a profession)	150	11.49	71	10.31	79	12.83
Secondary (trained in a profession)	10	0.77	4	0.58	6	0.97
College graduate (Bachelor's degree)	255	19.54	136	19.74	119	19.32
Post-graduate (Master's degree)	275	21.07	147	21.34	128	20.78
Doctoral degree	70	5.36	26	3.77	44	7.14
Missing data	6	0.46	0	0	6	0.97
Total	1305	100	689	100	616	100

M-W U test, p =0.02). Nearly one third of sub-adults are represented by children in the age category of 8- and 9-years-old, followed by the subsequent age category of children aged 10 and 11 (app. 29 %). There is a significant lack of older teens relative to the younger age groups (Table 5). Similar to the adults, sub-adult age categories were shown to be balanced as far as the male-to-female distribution was concerned (χ^2=10.20, p = 0.18).

There is a striking predominance of sub-adults with Czech nationality. Only 36 individuals aged less than 18 reported another nationality (Slovak in 9 cases) (Table 2).

Kinship database entries

There are 126 pairs of individuals (N of scans = 213) with documented kinships included in the database, of whom 74 pairs are siblings (24 pairs of sisters, 20 pairs of brothers, 30 pairs of brothers and sisters). The average age difference between relevant siblings is 2.62 years. Of

Table 5. Age-related distribution for sub-adult subjects included into the FIDENTIS Database

Age (years)	Total		Females		Males	
	n	%	n	%	n	%
<6	8	0.68	2	0.32	6	1.12
6-7	188	16.05	92	14.53	96	17.84
8-9	368	31.43	190	30.02	178	33.09
10-11	315	26.90	186	29.38	129	23.98
12-13	168	14.35	90	14.22	78	14.50
14-15	72	6.15	41	6.48	31	5.76
16-17	49	4.18	30	4.74	19	3.53
Missing data	3	0.26	2	0.32	1	0.19
Total	1171	100	633	100	538	100

the listed siblings, 14 pairs are twins, 5 pairs are of opposite sex, 5 pairs are females, and four pairs are males. In all but one pair, the twin participants are aged less than 18 years; the youngest pair is 7, and the oldest is 20.

An additional 52 pairs have a parent-and-offspring relationship. Mother-daughter and mother-son relationships are represented in 39 pairs and 5 pairs respectively. There are 2 father-son pairs and 6 father-daughter pairs. The age difference between a parent and corresponding offspring averaged to 27.06 years. (26.2 years if only mother-offspring relationships were regarded).

Multi-scan database entries

For a small portion of the database, multiple scans per individual are available (N=425). These multi-scan entries were acquired using different recording devices during one recording session and within a timespan of a few minutes (414 individuals for Vectra XT, 11 individuals for Vectra H1) (Table 6). Furthermore, in the course of building the database, 20 adult participants – 6 males, and 14 females aged between 19 and 36 (average 23.36 years) at the time of the first recording session – were examined at multiple occasions over a period of 4 years. For females, the average age was 23.07 years, while for males it was 27.20 years. For these individuals, 4 scans per person were collected. The interval between the first and the second session was approximately 2 years. The same participants were re-scanned by both M1 and XT Vectra devices within one day of each other.

Table 6. Device-specific distribution of 3D faces included into the FIDENTIS Database

Device	N	%
Vectra M1 only	1900	76.74
Vectra M1/XT	414	16.72
Vectra M1/H1	11	0.44
Vectra XT only	144	5.82
Vectra H1 only	7	0.28
Total	2476	100

Access to the database

The FIDENTIS Database is accessible via web interface at http://www.fidentis.cz/

database.php. The data included in the database are protected under Act No. 101/2000 Coll., on the protection of personal data. Full access to the database is restricted to members of the FIDENTIS research group. Two secured levels of the database are available to the public for non-commercial use by means of secure authentication.

Promo FIDENTIS 3D Face Database (Promo FIDENTIS Data)

The Promo FIDENTIS database is a set of exemplary 3D scans illustrating the content of the database. It is composed of examples of the original scanned data, associated documentation and generated average models for each of the demographic groups (males/females, and age groups) (Fig. 4, Fig. 5). Sample data to the real scan entries are also provided. Access is granted upon request. Interested parties must register by filling out a registration form and agreeing with the Terms of Use. Registered users are authorized to access the Promo FIDENTIS Database an unlimited number of times.

Extended Public FIDENTIS 3D Face Database

The Extended Public FIDENTIS 3D Face Database is a licensed version of the database and associated documentation. The accessible portion of the database is composed of 200 Vectra M1-generated facial scans of adult individuals (of whom 117 are females and 83 are males) with associated sets of landmarks and documentation. The average age is 26.12 years – 25.06 years for females, 27.60 years for males (no statistically significant differences, M-W U test, p =0.54). Additional demographic characteristics are listed in Tables 7 to 9.

In addition to the single-scan entries, a set of 80 scans corresponding to the multi-scan entries as described above has been included in the licensed database.

In order to receive access to the licensed dataset, applicants are requested to present their project to the research team leaders or to specify their intentions with the dataset adequately and to sign the License Agreement for the Extended Public FIDENTIS 3D Face Database, available online for download.

Licensed dataset vs. total database

If tested against distributions in the total database, demographic characteristics of the licensed dataset showed a statistically significant deviation for age category, education, sex in conjunction with age category, nationality and education. This is understandable given the abundance of subadults in the total database. If restricted to the adult portion of the database, only the sex category combined with the education level was shown as statistically significant, where females were slightly underrepresented in some of the education categories (e.g. high school graduation or doctoral degree). In addition, the sex distribution is skewed towards females to a larger extent in the Extended Database in comparison to the total database (Table 10).

Discussion

The human face conveys a large amount of information about a person's identity, ethnicity, kinship, emotional state, heath conditions, social status, mate choices, and fashion preferences, e.g., (Šrubař et al. 2015, Fink et al. 2007; Ekman and Friesen 1971; Alley 2013). These data are constantly processed during our ev-

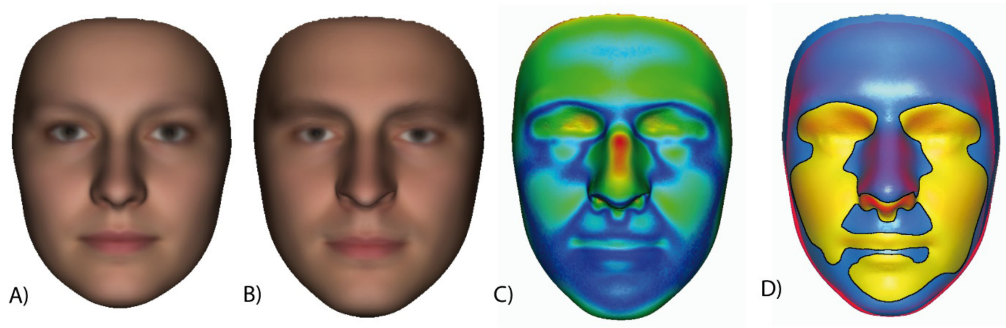

Fig. 4. Average female (A) and male (B) 3D face as computed from the set of adults included into the Extended Public FIDENTIS 3D Face Database. Sex-related differences displayed as color-coded absolute closest point-to-point distances (C) and superimposed models with contour rendering and fog simulation (D)

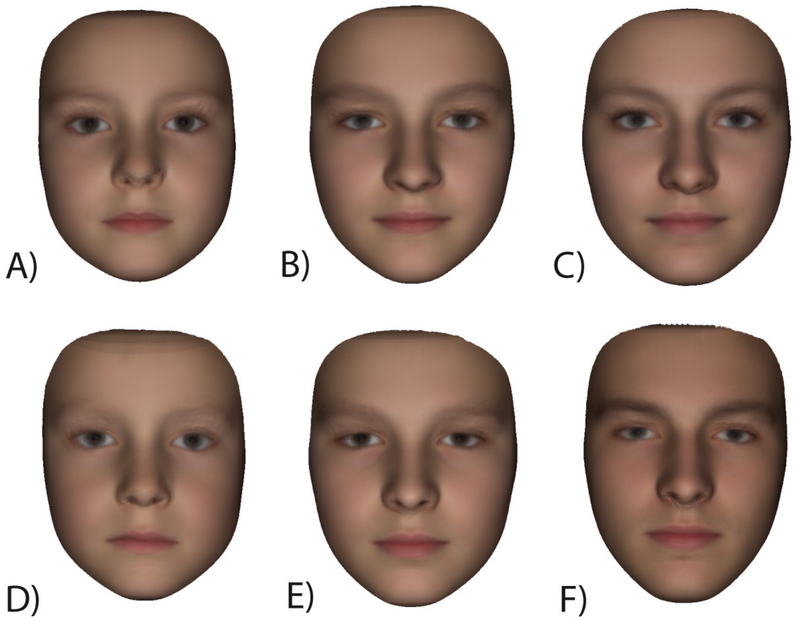

Fig. 5. Average female (upper row) and male 3D faces (lower row) as computed from the set of sub-adults included into the FIDENTIS 3D Face Database. Displayed are average models for age categories 6 to 7 years old (A, D), 12 to 13 years old (B, D) and 16 to 17 years old (C, E)

Table 7. The licensed Extended FIDENTIS database entries grouped nationality-wise

Nationality	Total		Females		Males	
	n	%	n	%	n	%
Czech	154	77.00	87	74.36	67	80.72
Slovak	45	22.50	30	25.64	15	18.07
Greek	1	0.50			1	1.20
Total	200	100	117	100	83	100

Table 8. The licensed Extended FIDENTIS database entries grouped into age categories

Age category (years)	Total		Females		Males	
	n	%	n	%	n	%
18-19	19	9.50	15	12.82	4	4.82
21-29	150	75.00	89	76.07	61	73.49
30-39	18	9.00	8	6.84	10	12.05
40-49	9	4.50	2	1.71	7	8.43
50-59	3	1.50	2	1.71	1	1.21
>=60	1	0.50	1	0.86		
Total	200	100	117	100	83	100

Table 9. The licensed Extended FIDENTIS database entries grouped according to their achieved education level

Achieved level of education	Total		Females		Males	
	n	%	n	%	n	%
Primary	8	4.00	7	5.98	1	1.20
Secondary (high school graduation)	70	35.00	48	41.03	22	26.51
Secondary (certified in a profession)	22	11.00	10	8.55	12	14.46
Secondary (trained in a profession)	1	0.50			1	1.21
Graduate (Bachelor's degree)	46	23.00	24	20.51	22	26.51
Post-graduate (Master's degree)	43	21.00	23	19.66	20	24.10
Post-graduate (doctoral degree)	10	5.00	5	4.27	5	6.02
Total	200	100	117	100	83	100

Table 10. Results of chi-square statistics comparing the total and licensed datasets

Variable	Against total database		Against adults	
	Pearson Chi-square	*p*-value	Pearson Chi-square	*p*-value
Sex	2.281	0.131	3.083	0.079
Age category	208.653	0.001*	7.678	0.262
Nationality	40.617	0.488	15.391	0.994
Education	202.936	0.001*	6.437	0.490
Sex/Age category	246.765	0.001*	28.891	0.068
Sex/Nationality	114.840	0.710	86.250	0.775
Sex/Education	233.749	0.001*	35.659	0.033*

*refers to statistically significant results at 5% level of accuracy

eryday activities. As a result of their biological, cultural and social impact, face data have been researched abundantly in various disciplines. In clinical as well as research-oriented settings, however, face processing relies heavily on the quality of data resources. Typically, these resources come from either in-house datasets or databases that have been made public.

The present paper introduces a novel dataset of 3D faces to the research community. It has been well-established that 3D face recordings surpass traditional recording modalities (traditional photographs or video recordings) on various levels. A three-dimensional representation allows for the display and processing of all three dimensions of a face equally and without one of them being discarded or distorted. It compensates for the lack of depth in traditional photographs, which creates difficulties for recognizing faces in a holistic manner, and reduces the ability to ascertain the topography of separate facial features (Eng et al. 2017). Ultimately, given an easy conversion between 3D and 2D data, it provides a good starting point for the examination of both 3D and 2D faces and face-related processes (Ferková et al. 2017).

One of the obvious benefits offered by a large database is that it allows full control over the process of data acquisition and unlimited access to the collected data. To date, the present research has been conducted exclusively within the FIDENTIS research group. Our first intentions with 3D faces were to gather training and test datasets for developing algorithms for face recognition (Urbanová and Chalás 2016), image face identification (Urbanová 2016), 3D face reconstruction (Ferková et al. 2017), and 3D face visualizations (Furmanová et al. 2017). However, the original design has evolved beyond these postulates. With a broader range of applications in mind, we now add new database entries with the intention that they will serve as a large-scale reference sample for mapping facial morphology of the current European population, as well as a dataset for age change assessment.

Yet, building a sizable image dataset available to the public is a tricky task. The collected data are sensitive, personal, identity-revealing, and therefore protected under local laws. As a result, they need to be carefully curated, limited to stated purposes only, and shared in a manner which would follow lawful data protection principles. To date, no published dataset has included more than 500 subjects, except for the ND2006 Face Database. Our database greatly exceeds these parameters. It is also the first and only existing 3D face dataset describing the facial morphology of Central Europeans in such scale.

Still, the public portion of the database, as presented here, cannot compete with other sizable public datasets. The reasons for reducing the number of subjects for public release are relatively straightforward. First, although taken for one of the most significant assets of the dataset, no face scans of sub-adults have been made public due to ethics standards, data sensitivity and respect for privacy. There are no specific plans for expanding the next-generation public datasets with any of the scanned children and adolescents. Averaged 3D images for seven sub-adult age groups, where the true identity of the subjects is obscured, are currently available for both males and females. We are determined to extend this dataset with additional exemplary models as soon as possible.

For the purpose of the database the age of 18 years was set to demarcate adulthood. This is generally the age of majority in many jurisdictions, including the US and European countries, despite the fact that the growth and development of facial skeletal structures may not be completely finished by age 18. In males, particularly, many skeletal features undergo the so-called extended maturation, which may extend skeletal growth until the age of 25 (Burke and Beard 1979).

The second reason for reducing the number of subjects is that this is the first public release of the database sample. To secure an optimal level of data diversity, proper data management, and storage capacities, and to maintain quality datasets featuring complete and error-free data with a user-friendly distribution, requires time-intensive and human resource-related efforts. We believe that the striking disproportion between the total and licensed database will be lessened in upcoming releases. Meanwhile, releasing the total dataset of collected 3D landmarks without the identity-sensitive 3D faces might serve as an appropriate, yet relatively effortless, manner of sharing valuable data.

Despite our best efforts, there are certain inherent limitations associated with the dataset which are worth noting:

Firstly, the database is highly skewed towards young adult individuals. This is consistent with other available face databases, as they are reflective of their origins within academia, where cohorts of young adults, undergraduate and graduate students are typical participants in scientific experiments and other research activities. For instance, the average age for participants in the Basel Face Model database is 24.97 years, which is less than the average age recorded for adults in both the total and public datasets.

It is worth mentioning that throughout the data acquisition, we have made several attempts to balance the age discrepancies within the database. After having notified the general public of the research and its purposes and potentials via media and publicity events, a new batch of participants has been added. Still, the lack of older individuals relative to the present-day Czech population remains evident.

Secondly, unlike other datasets, e.g., Binghamton University 3D Facial Expression Database (BU3DFE), the subjects included in the FIDENTIS database are of relatively uniform ethnic background. Again, this is due to the current demographics of Central Europe. The majority of inhabitants of the Czech Republic are ethnically and linguistically Czechs, an ethic group of Slavic origin and Caucasian ancestry. Most other ethnic groups included in the database are also Slavic (Slovaks, Poles, Ukrainians, Russians). While the current ethnic structure of the database is consistent with the general Czech population, in terms of ethnicity or ancestry it may not represent an appropriate sample for tasks targeted at other world populations with a different or more complex ethnic makeup.

Thirdly, the achieved level of education recorded for the subjects is higher than the national average. Again, this bias occurred due to the inception of the database within academic settings, where college students and graduates are more likely to participate.

Fourthly, the recorded facial geometry may not be consistent with that acquired by other modalities or recording systems, e.g., cone-beam CT, low-end facial scanners etc. All facial scans included in the database have been collected with Vectra optical scanners. Generally, these devices are classified among passive stereophotogrammetry-based systems (error 0.1 mm, 1.2 mm geometry resolution), with a reasonable capture and processing speed (3.5 ms, 80 s respectively) and equally reasonable file size (Tzou et al. 2014). They represent a rapid manner of collecting 3D surface data. They are also widely employed systems allowing patients or participants to avoid potentially harmful diagnostic techniques, such as X-rays or computed tomography (Rosati et al. 2010; Kustár 2013). Still, database users should be cautious while combining the present dataset and 3D faces of differing resolution from other sources.

Fifthly, the post-processing treatment (merging, pose-standardization, editing) may have affected the recorded geometry. 3D technologies offer many benefits over more conventional approaches. However, they are often noisy and result in incomplete scans, and hence dependent on time-demanding and laborious post-processing phases. The data acquired by the Vectra systems are no exception. As a result, we purposely included various types of spatial data with a range of editing and modifications. The majority of them were processed automatically or semi-automatically. Some of the adjustments, such as the collection of facial landmarks, were made manually. If necessary, database users are encouraged to process edit-free models or modify (edit or merge) the raw 3D images accordingly.

Conclusion

We presented a sizable 3D face database, of which a portion has been made publicly available to the scientific community. Currently, the database represents the largest 3D face dataset of a European population. The publicly licensed portion of the database composed of 200 adult subjects is available for download upon request. The data are intended for non-commercial use only. Additional public releases of the database are expected soon.

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Authors' contributions

The first author (PU) conceived of the database, served as team leader for the research project, wrote the draft and approved the final manuscript; remaining authors served as investigators for the project and they were involved in data acquisition and data management. They were also essential in drafting the manuscript. All authors contributed to approve the final version of the manuscript.

Conflict of interests

The authors declare that they have no conflicts of interest in the research.

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