Anthropometry documentation for: *Toward a Novel Set of Pinna Anthropometric Features for Individualizing Head-Related Transfer Function*

Davide Fantini[1*], Federico Avanzini[1], Stavros Ntalampiras[1], Giorgio Presti[1]

[1]Laboratory of Music Informatics (LIM),
Department of Computer Science,
University of Milan,
Italy.

*Corresponding author(s). E-mail(s): davide.fantini@unimi.it;
Contributing authors: federico.avanzini@unimi.it; stavros.ntalampiras@unimi.it;
giorgio.presti@unimi.it;

Contents

This documentation provides a detailed description of the procedure used to measure pinna anthropometric parameters from pinna landmarks and pinna depth images described in the publication [1]. Fig. 1 shows a scheme of the pinna with its parts to help the reader. The procedure for extracting the anthropometric parameters described in this documentation can be replicated using the Matlab code we provide in a public repository [2].

The landmarks annotation scheme is shown in Fig. 3b, Fig. 4 and Fig. 2. The landmarks are grouped based on the parts of the pinna shape on which they are placed: outer helix (blue landmarks), concha (purple landmarks), fossa triangularis (orange landmarks), and inner helix (yellow landmarks). The figures also depict the starting and ending landmarks indices of each pinna shape part.

For the sake of clarity, in the following, we will use terms such as "low" and "high", or "inferior" and "superior", to refer to values in the y coordinate (e.g., the *lobulus* is positioned lower in the pinna compared to the fossa triangularis). Conversely, "left" and "right" will be used to refer to values in the x coordinate (the tragus is on the right of the helix). Thus, we assume that the pinna is oriented as in Fig. 3b, Fig. 4 and Fig. 2.

The documentation is structured as follows. Section 1 describes the estimation of the pinna characteristic points, while Section 2 focuses on the pinna cavities. The anthropometric parameters are described in five categories: distance parameters (Section 3), angle parameters (Section 4), area parameters (Section 5), volume parameters (Section 6), depth parameters (Section 7). Finally, an overview of all the anthropometric parameters can be found in Table 1.

1 Pinna characteristic points

Using the pinna landmarks and the pinna depth image, we can estimate two characteristic points of the pinna: the tragus position $\mathbf{t}$ and the helix position $\mathbf{h}$ at the same height as the tragus.

1.1 Tragus

In our measurement procedure, the tragus position $\mathbf{t}$ serves as an important reference point for measuring several anthropometric parameters. An initial estimate $\mathbf{t}'$ of the tragus position is given by the position of a predefined landmark. This landmark has been selected as it represents the best matching position of the tragus in the annotation scheme. Then, a more robust estimation of $\mathbf{t}$ is obtained by outlining a rectangular area $A_{\mathbf{t}}$ around the initial estimate $\mathbf{t}'$. The width and height of $A_{\mathbf{t}}$ are equal to the 15% and 10% of the extension in x and y coordinates of the pinna landmarks, respectively. The area $A_{\mathbf{t}}$ is not centered around $\mathbf{t}'$ but is slightly displaced upward and to the right in order to exclude the antitragus. The tragus position $\mathbf{t}$ is estimated as the point in $A_{\mathbf{t}}$ with the maximum value in the z coordinate.

1.2 Helix

The helix position $\mathbf{h}$ is another important reference for some anthropometric parameters. In our measurement procedure, we estimated the position of the helix at the same height (y coordinate) of the tragus. To do so, we performed a horizontal slice of the pinna depth image at $\mathbf{t}_y$, the y coordinate of $\mathbf{t}$, as shown in Fig. 5b. Then, the helix position $\mathbf{h}$ is estimated as the point with the maximum z coordinate value in this horizontal slice.

2 Pinna cavities

Given the pinna landmarks, three pinna cavities are automatically outlined: cavum conchae C_1, cymba conchae C_2, and fossa triangularis C_3. These cavities are shown in the pinna scheme in Fig. 1, while in Fig. 2 we show how we extracted them on an example pinna depth image.

2.1 Cavum conchae

The cavum conchae cavity C_1 is concha part below the crus helicis including the incisura intertragica as shown in Fig. 1. The cavity C_1 outlined on an example ear with our procedure is shown in Fig. 2.

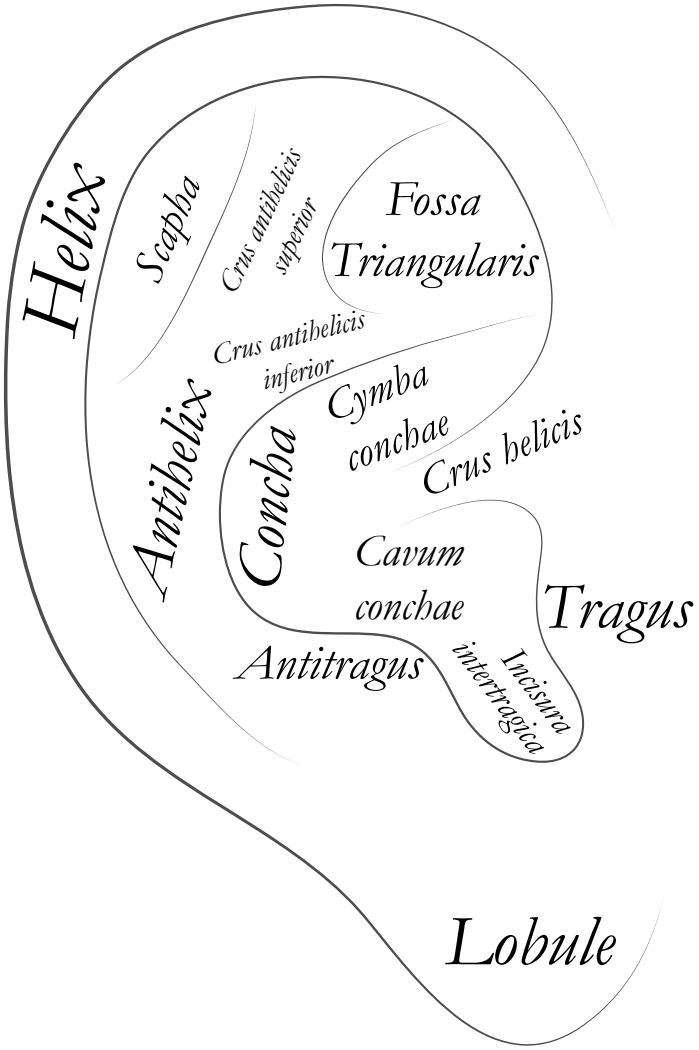


Fig. 1: Pinna scheme with the names of the pinna parts. Names adapted from [3, Fig. 704].

We have selected the landmarks belonging to C_1 as a subset of the landmarks outlining the concha (purple landmarks). The starting landmark of C_1 is the first of the concha landmarks (landmark index 50) placed on the lower part of the crus helicis. Then, the adjacent concha landmarks are selected outlining the inferior part of the crus helicis, reaching the tragus, followed by the incisura intertragica, the antitragus and, finally the inferior part of the antihelix. The last landmark of C_1 is the one on the antihelix that has the closest y coordinate value to the first landmark (index 50). These selected landmarks define the pinna cavity C_1.

2.2 Cymba conchae

The cymba conchae cavity C_2 is the concha part above the crus helicis as shown in Fig. 1. The cavity C_2 outlined on an example ear with our procedure is shown in Fig. 2. We selected the landmarks belonging to C_2 as a subset of the landmarks outlining the concha (purple landmarks) and the inner helix (yellow landmarks). Among the inner helix landmarks, we selected those starting from the first landmark (index 136) on the superior part of the crus helicis to the one just below (y coordinate) the last landmark (index 117, the one closer to the inner helix) of those outlining the concha. Then, among the concha landmarks, we started from the last landmark of those that outline the concha (index 117) and we selected the previous ones (following the crus antihelicis inferior) until the landmark just

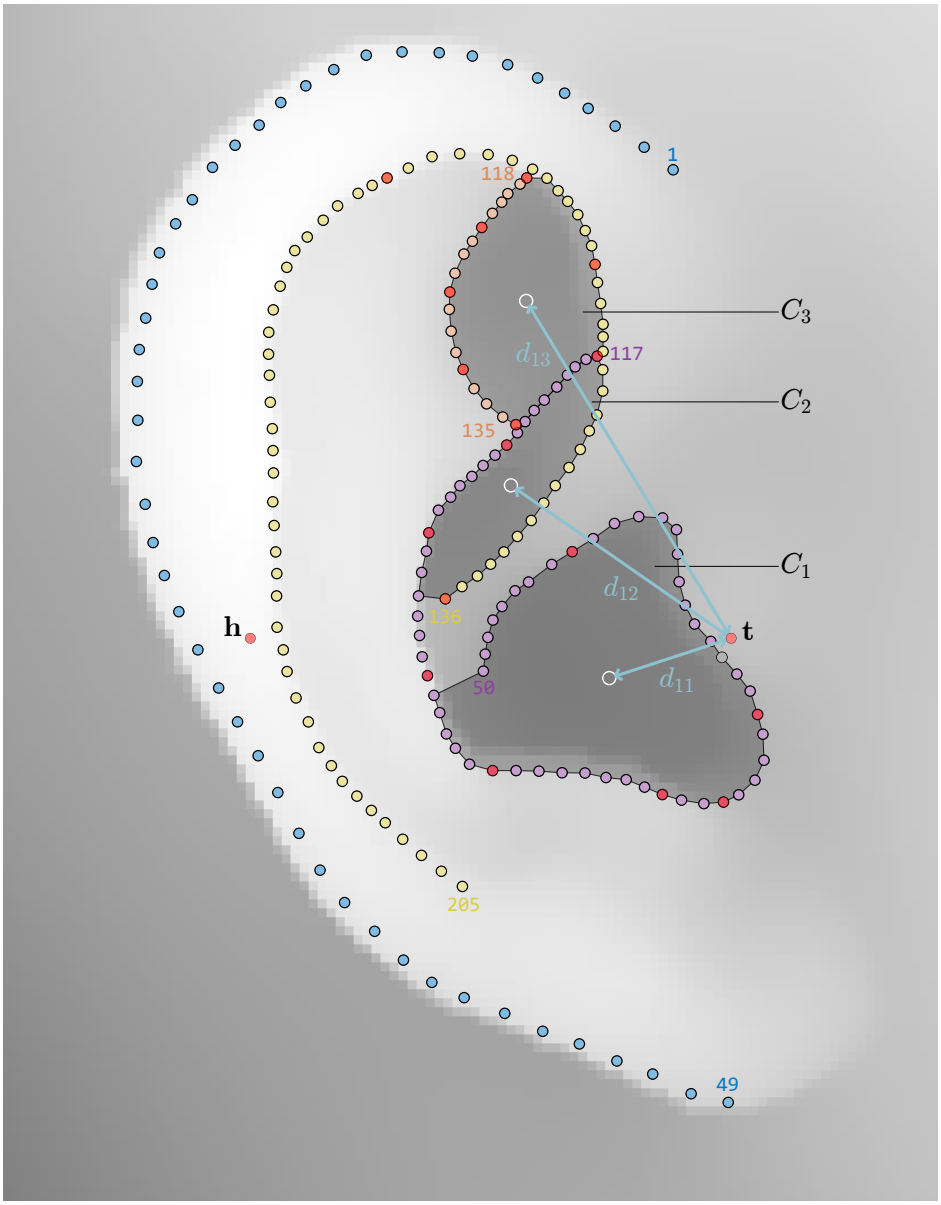
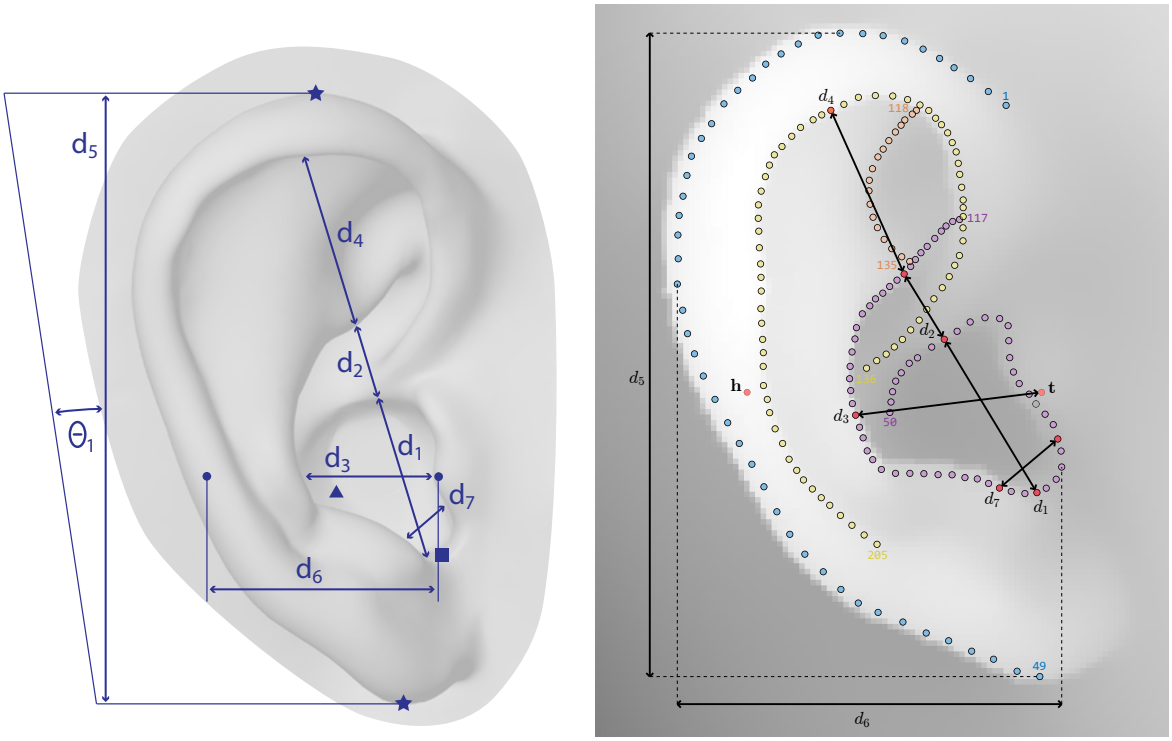


Fig. 2: Pinna cavities C_{1-3} as extracted in our work along with the anthropometric parameters d_{11-13} representing the distance between the tragus **t** and the cavities' centroids. The landmarks are colored according to the pinna shape part and the numbers on the first and last landmarks of each shape part indicate the annotation order. The grayscale colormap represents the depth (z) values.

above (y coordinate) the first landmark (index 136) on the crus helicis among those on the inner helix. These selected landmarks define the pinna cavity C_2.

2.3 Fossa triangularis

The fossa triangularis cavity C_3 is the pinna cavity enclosed by the helix and the *crus antihelicis* inferior and superior as shown in Fig. 1. The cavity C_3 outlined on an example ear with our procedure is shown in Fig. 2. We selected the landmarks belonging to C_3 as a subset of the landmarks outlining the concha (purple landmarks) and the inner helix (yellow landmarks), in addition to all the landmarks outlining the fossa triangularis (orange landmarks). The concha and inner helix landmarks are selected to form an closed region with the fossa triangularis landmarks. Among the concha landmarks (purple),



(a) HUTUBS pinna anthropometry

(b) Measured HUTUBS pinna anthropometry

Fig. 3: Comparison between (a) HUTUBS pinna anthropometric parameters d_{1-7} and θ_1 in the measurement scheme retrieved from [4] with (b) an example of how we measured the HUTUBS pinna anthropometric parameters d_{1-7} in our work (black arrows between red landmarks). The landmarks are colored according to the pinna shape part and the numbers on the first and last landmarks of each shape part indicate the annotation order. The grayscale colormap represents the depth (z) values.

the first landmark is the one closest to the first fossa triangularis landmark (index 135, the one with the lowest y coordinate). The last landmark is the last of the concha landmarks (index 117, the one closer to the inner helix). Among the inner helix landmarks (yellow), we selected those starting from the landmark just above (y coordinate) the last of the landmark outlining the concha (index 117), to the landmark just below (y coordinate) the top landmark of the fossa triangularis (index 118, the one with the highest y coordinate). These selected landmarks define the pinna cavity C_3.

3 Distance parameters

The distance parameters defined in the HUTUBS specification are shown in Fig. 3 (d_{1-7}) and Fig. 5 ($d_{8,9}$). We neglected the d_{10} HUTUBS parameter because we were unable to replicate its measurement. The novel distance parameters are shown in Fig. 4 (d_{14-21}, between predefined landmarks) and Fig. 2 (d_{11-13}, between **t** and pinna cavity centroids).

d_1: cavum conchae height

The HUTUBS parameter d_1 represents the height of the cavum conchae. In the HUTUBS specification, d_1 is measured as the distance between the lowest point of the incisura intertragica and the edge between the *cavum concha* and the crus helicis.
In our measurement procedure, we have chosen a pair of landmarks that approximate the distance d_1 as closely as possible, as shown in Fig. 3. The inferior measurement landmark is placed on the lower part of the incisura intertragica. The superior measurement landmark is one of those separating the cavum conchae from the crus helicis.

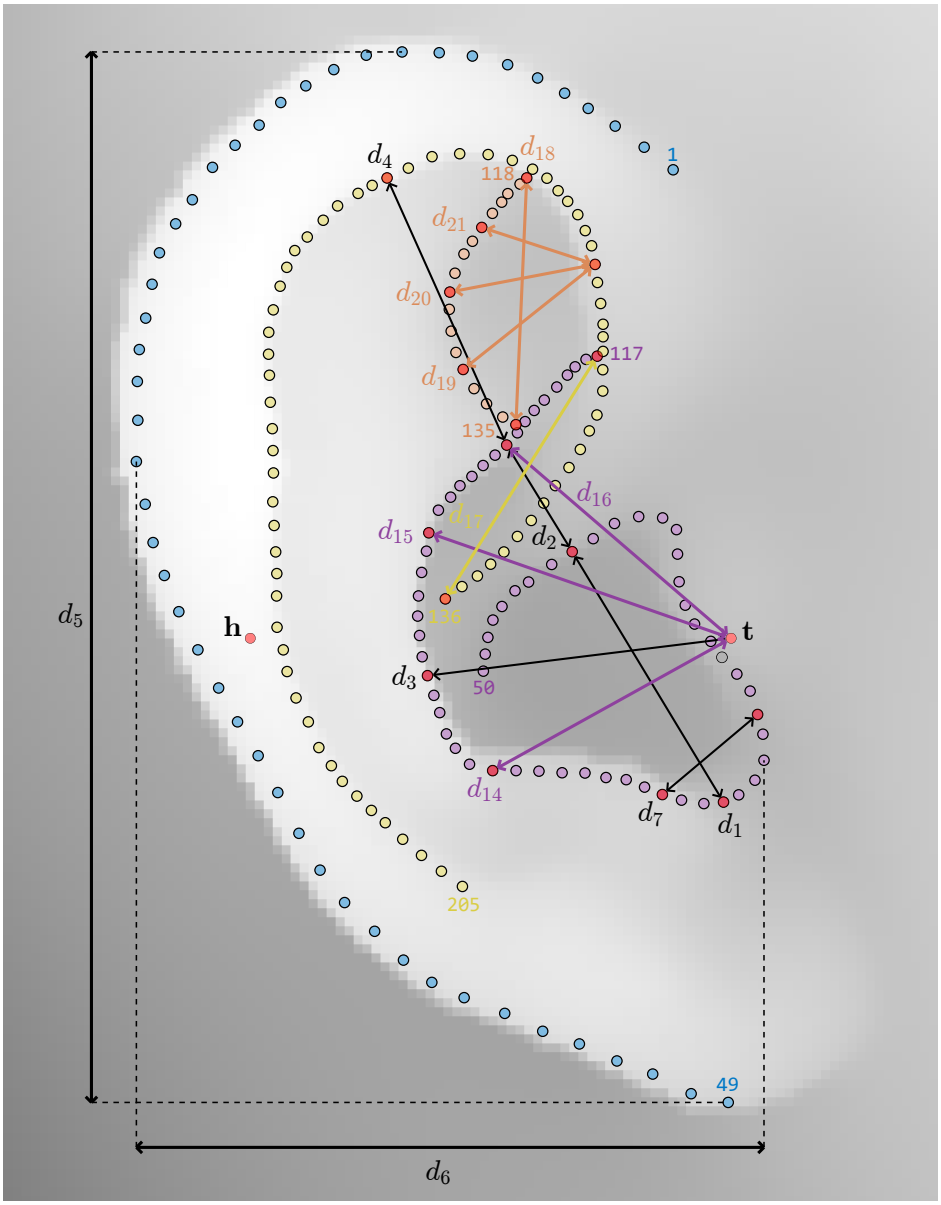


Fig. 4: Proposed pinna anthropometric parameters d_{14-21} along with the HUTUBS pinna anthropometric parameters d_{1-7} as measured in our work. The landmarks are colored according to the pinna shape part and the numbers on the first and last landmarks of each shape part indicate the annotation order. The grayscale colormap represents the depth (z) values.

d_2: cymba conchae height

The HUTUBS parameter d_2 represents the height of the cymba conchae. In the HUTUBS specification, d_2 is measured as the distance between the edge separating the cymba conchae and the crus helicis—the upper measurement point of d_1—and the edge between the cymba conchae and the crus antihelicis inferior.

In our measurement procedure, we have chosen a pair of landmarks that approximate the distance d_2 as closely as possible, as shown in Fig. 3. The inferior measurement landmark corresponds to the superior landmark of d_1. The superior measurement landmark is placed on the border of the cymba conchae with the crus antihelicis inferior close to the edge of the fossa triangularis.

d_3: cavum conchae width

The HUTUBS parameter d_3 represents the width of the cavum conchae. In the HUTUBS specification, d_3 is measured as the distance between the tragus and the point on the opposite side of the cavum conchae.
In our measurement procedure, we have chosen a pair of landmarks that approximate the distance d_3 as closely as possible, as shown in Fig. 3. The measurement landmark on the right is the estimated tragus position $\mathbf{t}$. The measurement landmark on the left is placed on the cavum conchae edge opposite the tragus. This landmark has been selected to obtain an approximately horizontal measurement line.

d_4: fossa height

The HUTUBS parameter d_4 represents the height of the fossa triangularis measured as the distance from the edge between the cymba conchae and the antihelix—superior measurement point of d_2—to the edge between the helix and the antihelix, specifically the *crus antihelicis superior*.
In our measurement procedure, we have chosen a pair of landmarks that approximate the distance d_4 as closely as possible, as shown in Fig. 3. The inferior measurement landmark corresponds to the superior landmark of d_2. The superior measurement landmark is the landmark on the top of the inner edge of the helix (yellow landmarks).

d_5: pinna height

The HUTUBS parameter d_5 represents the height of the pinna. In the HUTUBS specification, d_5 is measured as the distance between the upper and the lower points of the entire pinna using a vertical measurement segment.
Similarly, in our procedure, the pinna height d_5 was measured as the distance in y coordinate between the landmarks with the maximum and minimum y coordinate values, as shown in Fig. 3.

d_6: pinna width

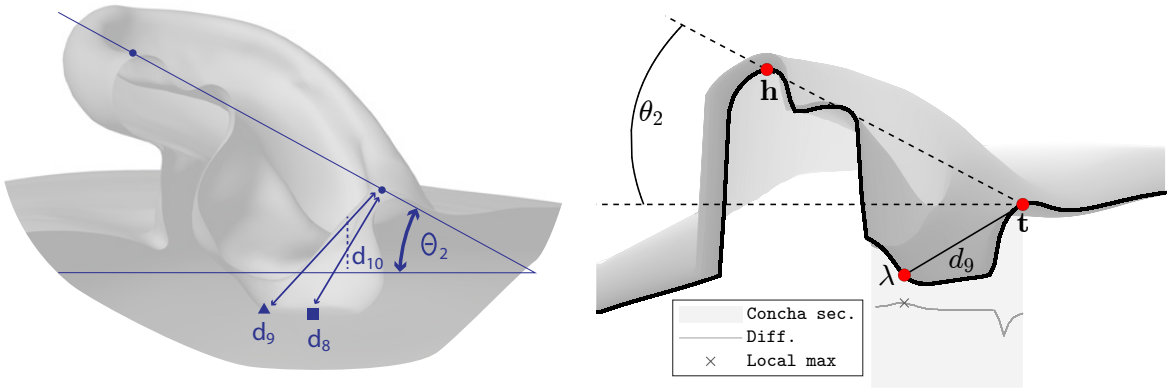
The HUTUBS parameter d_6 represents the width of the pinna. In the HUTUBS specification, d_6 is measured as the distance between the tragus and a point on the helix at the same height as the tragus. Conversely, to obtain a more robust measurement in our procedure, the pinna width d_6 was measured as the landmarks' width range, i.e. the distance in x coordinate between the landmarks with the maximum and minimum x coordinate values, as shown in Fig. 3.

d_7: intertragal incisure

The HUTUBS parameter d_7 represents the width of the incisura intertragica. In the HUTUBS specification, d_7 is measured as the distance between a point below the tragus and a point on the antitragus. In our measurement procedure, we have chosen a pair of landmarks that approximate the distance d_7 as closely as possible, as shown in Fig. 3. The measurement landmark on the right is below the tragus in a position close to the one of HUTUBS specification as well as the measurement landmark on the left which is placed on the antitragus.

d_8: cavum conchae depth (down)

The HUTUBS parameter d_8 represents the cavum conchae depth measured as the distance in 3D between the tragus and a point in the incisura intertragica placed on the surface of the cavum conchae. For the definition of d_8 in HUTUBS specification, ser Fig. 3a and Fig. 5a.
The d_8 measurement for an example pinna is shown in Fig. 6 in a 3D view. In our procedure, d_8 is measured as the distance in 3D (x, y, z coordinates) between the tragus position $\mathbf{t}$ and the deepest (lowest z coordinate value) point found in an area A_{d_8} of the incisura intertragica. The area A_{d_8} is outlined as a small square section centered in the inferior measurement landmarks of d_1. The side of the A_{d_8} is equal to the 5% of the extension in x coordinate of the pinna landmarks.



(a) HUTUBS pinna anthropometry

(b) Proposed pinna anthropometry

Fig. 5: Horizontal section of the pinna comparing (a) the HUTUBS pinna anthropometric parameters d_{8-10} and θ_2 in the measurement scheme retrieved from [4] with (b) a scheme of how we measured the HUTUBS pinna anthropometric parameters d_9 and θ_2 in our work. In (b) the light gray area represents the concha section, while the gray line in this section represents the difference between adjacent elements of this section, and the cross is the local maxima.

d_9: cavum concha depth (back)

The HUTUBS parameter d_9 represents the cavum conchae depth measured as the distance in 3D between the tragus and the corner between the concha surface and the antihelix wall. The HUTUBS measurement scheme for d_9 is shown in Fig. 5a.
Examples of how we measured d_9 in our approach are shown with a horizontal section of the pinna in Fig. 5b and with a 3D view in Fig. 6. In our procedure, d_9 is measured as the distance in x and z coordinates between the estimated tragus position $\mathbf{t}$ and the point λ representing the corner between the concha surface and the antihelix wall. This point λ is estimated by a horizontal slice of the pinna depth image at $\mathbf{t}_y$, i.e., the y coordinate of the tragus position $\mathbf{t}$. In this horizontal slice, we focus on the concha section between the tragus and the antihelix wall (light gray area in Fig. 5b). The concha section is found by selecting the area to the left of the tragus with lower z values. Then, we compute the difference between the adjacent values of this concha section (gray line in the concha section in Fig. 5b) to highlight the corner between the concha and the antihelix. This corner is found by looking for the local maximum with the greater "prominence" in the concha section (cross in Fig. 5b) corresponding to λ, i.e. the measurement point of d_9. The local maxima are found via the Matlab function `islocalmax` [5] which also returns the "prominence" of the maxima, i.e. a value that measures how each maximum stands out compared to other maxima.

d_{11}: cavum conchae centroid

The parameter d_{11} represents the distance between the tragus and the centroid of the cavum conchae. The measurement of d_{11} on an example pinna depth image is shown in Fig. 2. In our procedure, we measured d_{11} as the distance in x and y coordinates between the estimated tragus position $\mathbf{t}$ and the centroid of the polygon formed by the landmarks of the cavum conchae cavity C_1.

d_{12}: cymba conchae centroid

The parameter d_{12} represents the distance between the tragus and the centroid of the cymba conchae. The measurement of d_{12} on an example pinna depth image is shown in Fig. 2. In our procedure, we measured d_{12} as the distance in x and y coordinates between the estimated tragus position $\mathbf{t}$ and the centroid of the polygon formed by the landmarks of the cymba conchae cavity C_2.

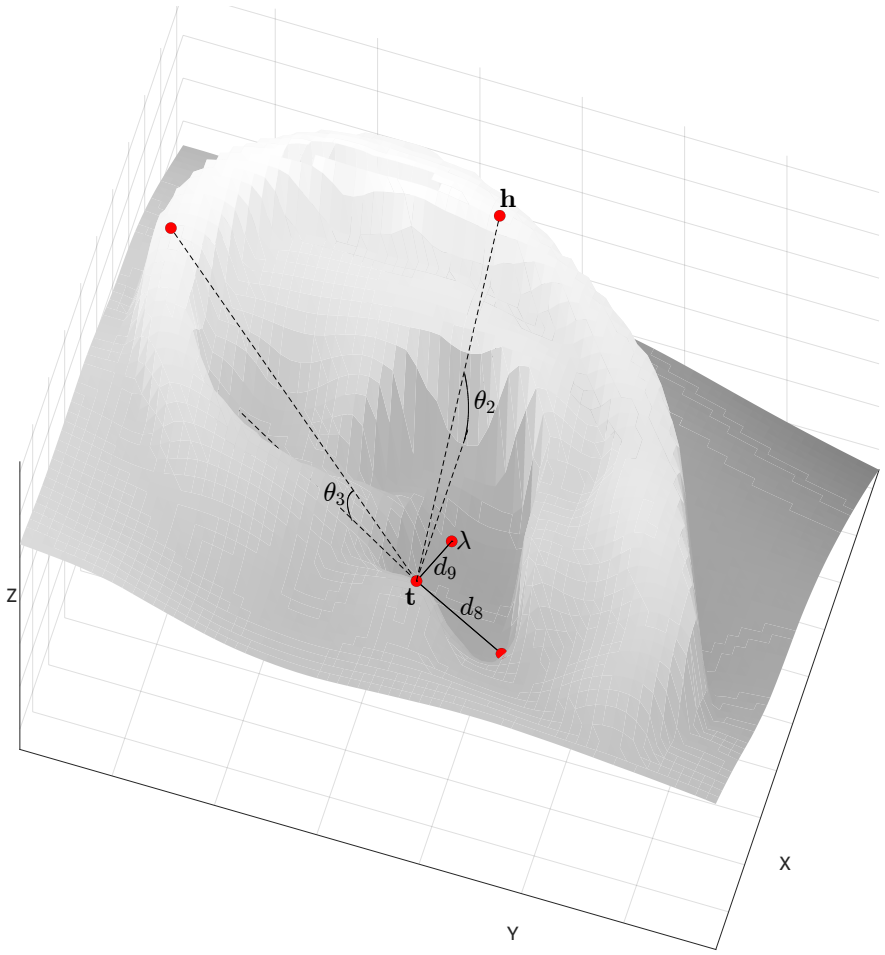


Fig. 6: 3D view of the pinna showing the measurements of the metrics d_8, d_9, θ_2 and θ_3 along with the tragus position **t** and the helix position **h**. The grayscale colormap represents the depth (z) values.

d_{13}: fossa triangularis centroid

The parameter d_{13} represents the distance between the tragus and the centroid of the fossa triangularis. The measurement of d_{13} on an example pinna depth image is shown in Fig. 2. In our procedure, we measured d_{13} as the distance in x and y coordinates between the estimated tragus position **t** and the centroid of the polygon formed by the landmarks of the fossa triangularis cavity C_3.

d_{14}: cavum conchae width (inferior)

The parameter d_{14} represents the cavum conchae width measured as the distance between the tragus and the convex corner of the concha formed by the junction of the antitragus with the antihelix.
The measurement of d_{14} on an example pinna depth image is shown in Fig. 4. In our procedure, we measured d_{14} as the distance in x and y coordinates between the estimated tragus position **t** and the landmark positioned on the described corner of the concha.

d_{15}: cavum conchae width (inferior)

The parameter d_{15} represents the cavum conchae width measured as the distance between the tragus and the convex corner of the concha formed by the junction of the antihelix with the crus antihelicis inferior.
The measurement of d_{15} on an example pinna depth image is shown in Fig. 4. In our procedure, we

measured d_{15} as the distance in x and y coordinates between the estimated tragus position $\mathbf{t}$ and the landmark positioned on the described corner of the concha.

d_{16}: cavum conchae height (tragus)

The parameter d_{16} represents the distance between the tragus and the edge between the cymba conchae and the crus antihelicis inferior.
The measurement of d_{16} on an example pinna depth image is shown in Fig. 4. In our procedure, we measured d_{16} as the distance in x and y coordinates between the estimated tragus position $\mathbf{t}$ and the superior landmark used for the measurement of d_2.

d_{17}: cymba conchae width

The parameter d_{17} represents the cymba conchae width.
The measurement of d_{17} on an example pinna depth image is shown in Fig. 4. In our procedure, we measured d_{17} as the distance in x and y coordinates between the first landmark (index 134) of those outlining the inner helix edge (yellow landmarks) and the last landmark (index 115) of those outlining the concha edge (purple landmarks).

d_{18}: fossa triangularis height

The parameter d_{18} represents the fossa triangularis height.
The measurement of d_{18} on an example pinna depth image is shown in Fig. 4. In our procedure, we measured d_{18} as the distance in x and y coordinates between the first (index 116) and the last (index 133) landmarks of those outlining the fossa triangularis edge (orange landmarks).

d_{20}: fossa triangularis width

The parameter d_{20} represents the fossa triangularis width.
The measurement of d_{20} on an example pinna depth image is shown in Fig. 4. In our procedure, we measured d_{20} as the distance in x and y coordinates between two landmarks. The left landmark is the middle one of those outlining the fossa triangularis edge (orange landmarks). The right landmark is selected as the landmark among those outlining the inner helix edge (yellow landmarks) placed in a central position with respect to the fossa triangularis. The latter landmarks represent a reference point for the width measurements of the fossa triangularis, similar to the tragus which is a reference for the concha measurements.

d_{19}: fossa triangularis width (inferior)

The parameter d_{19} represents the fossa triangularis width measured in the inferior part of the fossa triangularis.
The measurement of d_{19} on an example pinna depth image is shown in Fig. 4. In our procedure, we measured d_{19} as the distance in x and y coordinates between a selected pair of landmarks. The right one is the same reference used in the d_{20} measurement. The left one is placed between the left measurement landmark of d_{20} and the lower landmark (index 135) of those outlining the fossa triangularis.

d_{21}: fossa triangularis width (superior)

The parameter d_{21} represents the fossa triangularis width measured in the superior part of the fossa triangularis.
The measurement of d_{21} on an example pinna depth image is shown in Fig. 4. In our procedure, we measured d_{21} as the distance in x and y coordinates between a selected pair of landmarks. The right one is the same reference used in the d_{20} measurement. The left one is placed between the left measurement landmark of d_{20} and the upper landmark (index 118) of those outlining the fossa triangularis.

4 Angle parameters

The angle parameters θ_1 and θ_2 defined in the HUTUBS specification are shown in Fig. 3a and Fig. 5a, respectively. The angle parameters proposed in our paper are shown in Fig. 3b, Fig. 4 and Fig. 2 (angle parameters r_n related to the corresponding distance parameters d_n) and Fig. 6 (θ_3).

θ_1: pinna rotation angle

The HUTUBS parameter θ_1 represents the pinna rotation angle. In the HUTUBS specification, θ_1 is measured as the angle between the vertical axis and the line passing between the highest point on the helix and the lowest point on the *lobulus*, i.e. the same ones used to measure d_5, as shown in Fig. 3a. In our procedure, we measured θ_1 as the angle between the y axis and the line passing through the upper and lower landmarks of the pinna, i.e. those with the maximum and minimum y values, respectively. These landmarks are the same as those used to measure d_5. For the sake of space, in Fig. 3b, which represents our implementation of the HUTUBS parameters, we do not directly depict θ_1, although the y axis and the d_5 measurement landmarks are shown.

θ_2: pinna flare angle

The HUTUBS parameter θ_2 represents the pinna flare angle, measured as the angle between the view-axis of the subject (x axis) and the line passing between the tragus and the helix, as shown in Fig. 5a. Examples of how we measured θ_2 in our approach are shown with a horizontal section of the pinna in Fig. 5b and with a 3D view in Fig. 6. In our procedure, θ_2 is measured in the xz plane as the angle between the x axis and the line intersecting the tragus position $\mathbf{t}$ and the helix position $\mathbf{h}$, as shown in Fig. 5b.

θ_3: pinna upper roll

The parameter θ_3 represents the *pinna upper roll*, i.e. how much the superior part of the helix protrudes in the opposite direction of the head. The parameter θ_3 has been designed to complement the pinna flare angle θ_2.
In Fig. 6 we show how θ_3 is measured for an example pinna depth image. In our procedure, we measured θ_3 as the angle in the yz plane between the y axis and the line passing through the tragus $\mathbf{t}$ and the upper point of the helix. To ensure a robust measurement, the upper helix point is computed as the point between the two landmarks with the highest values in y coordinate among those outlining the outer (blue landmarks) and inner (yellow landmarks) helix.

r_n: distance segment's angle

The angle parameters r_n with $n = \{1, \dots, 21\} \setminus \{5, 6, 8, 9\}$ represent the angle formed by the measurement segments of the parameters d_n and the vertical axis used as reference.
In our procedure, we measured r_n as the angle in the xy plane between the y axis and the line passing through the two measurement landmarks used for d_n.

5 Area parameters

The area parameters represent the area of the polygons formed by the 2D landmarks (x and y coordinates) of the pinna cavities C_{1-3} shown in Fig. 2.

a_1: cavum concha area

The parameter a_1 represents the area in the xy plane of the pinna cavity C_1, i.e. the cavum conchae. Given the landmarks outlining the pinna cavity C_1, we defined a polygon with such landmarks as vertices. The area of the polygon is computed to obtain the parameter a_1.

a_2: cymba concha area

The parameter a_2 represents the area in the xy plane of the pinna cavity C_2, i.e. the cymba conchae. Given the landmarks outlining the pinna cavity C_2, we defined a polygon with such landmarks as vertices. The area of the polygon is computed to obtain the parameter a_2.

a_3: fossa triangularis area

The parameter a_3 represents the area in the xy plane of the pinna cavity C_3, i.e. the fossa triangularis. Given the landmarks outlining the pinna cavity C_3, we defined a polygon with such landmarks as vertices. The area of the polygon is computed to obtain the parameter a_3.

6 Volume parameters

The volume parameters represent the volume of the polyhedra Q_{1-3} formed by the 3D landmarks (x, y and z coordinates) of the pinna cavities C_{1-3} shown in Fig. 2, and the pixels of the depth image enclosed by such landmarks.

v_1: cavum concha volume

The parameter v_1 represents the volume of the cavum conchae cavity C_1. Given the 3D landmarks outlining the pinna cavity C_1 along with the depth image pixels enclosed by the landmarks, we computed the 3D convex hull of these points forming a polyhedron Q_1. The volume of the polyhedron Q_1 is computed to obtain the parameter v_1.

v_2: cymba concha volume

The parameter v_2 represents the volume of the cymba conchae cavity C_2. Given the 3D landmarks outlining the pinna cavity C_2 along with the depth image pixels enclosed by the landmarks, we computed the 3D convex hull of these points forming a polyhedron Q_2. The volume of the polyhedron Q_2 is computed to obtain the parameter v_2.

v_3: fossa triangularis volume

The parameter v_3 represents the volume of the fossa triangularis cavity C_3. Given the 3D landmarks outlining the pinna cavity C_3 along with the depth image pixels enclosed by the landmarks, we computed the 3D convex hull of these points forming a polyhedron Q_3. The volume of the polyhedron Q_3 is computed to obtain the parameter v_3.

7 Depth parameters

The depth parameters represent the maximum depth of the polyhedra Q_{1-3} formed by the 3D landmarks (x, y and z coordinates) of the pinna cavities C_{1-3} shown in Fig. 2, and the pixels of the depth image enclosed by such landmarks.

h_1: cavum concha

The parameter h_1 represents the depth of the cavum conchae cavity C_1. Given the points defining the previously defined polyhedron Q_1, which represents the pinna cavity C_1 in 3D, we computed the depth h_1 as the maximum range in z coordinate of the vertices of the polyhedron Q_1.

h_2: cymba concha depth

The parameter h_2 represents the depth of the cymba conchae cavity C_2. Given the points defining the previously defined polyhedron Q_2, which represents the pinna cavity C_2 in 3D, we computed the depth h_2 as the maximum range in z coordinate of the vertices of the polyhedron Q_2.

h_3: fossa triangularis depth

The parameter h_3 represents the depth of the fossa triangularis cavity C_3. Given the points defining the previously defined polyhedron Q_3, which represents the pinna cavity C_3 in 3D, we computed the depth h_3 as the maximum range in z coordinate of the vertices of the polyhedron Q_3.

References

[1] Fantini, D., Ntalampiras, S., Presti, G., Avanzini, F.: Toward a novel set of pinna anthropometric features for individualizing head-related transfer function. In: Sound and Music Computing Conference (2024)

[2] Davide Fantini: pinna-anthropometry-extraction (2024). https://github.com/DavideFantini/pinna-anthropometry-extraction

[3] Cunningham, D.J., Robinson, A.: Cunningham's Textbook of Anatomy, 4th edn., p. 1636. W. Wood, New York (1914)

[4] Brinkmann, F., Dinakaran, M., Pelzer, R., Wohlgemuth, J.J., Fabian, S., Voss, D., Grosche, P., Weinzierl, S.: The HUTUBS head-related transfer function (HRTF) database (2019). https://doi.org/10.14279/depositonce-8487

[5] MathWorks, Inc.: islocalmax (R2023b). https://www.mathworks.com/help/matlab/ref/islocalmax.html

Table 1: Overview of the pinna anthropometric parameters. For each parameter, we report the name, the type of measurement, the coordinates involved in the measurement, the mean and the standard deviation, and the unit of measurement.

Parameter	Name	Type	Coordinates	Mean ± St. Dev.	Unit
d_1	cavum conchae height	distance	xy	1.67 ± 0.19	cm
d_2	cymba conchae height	distance	xy	0.88 ± 0.14	cm
d_3	cavum conchae width	distance	xy	1.73 ± 0.24	cm
d_4	fossa height	distance	xy	1.59 ± 0.31	cm
d_5	pinna height	distance	xy	5.99 ± 0.39	cm
d_6	pinna width	distance	xy	3.25 ± 0.37	cm
d_7	intertragal incisure	distance	xy	0.56 ± 0.14	cm
d_8	cavum conchae depth (down)	distance	xyz	1.36 ± 0.26	cm
d_9	cavum concha depth (back)	distance	xz	1.36 ± 0.21	cm
d_{11}	cavum conchae centroid	distance	xy	0.8 ± 0.12	cm
d_{12}	cymba conchae centroid	distance	xy	1.48 ± 0.2	cm
d_{13}	fossa triangularis centroid	distance	xy	2.14 ± 0.24	cm
d_{14}	cavum conchae width (inferior)	distance	xy	1.48 ± 0.22	cm
d_{15}	cavum conchae width (superior)	distance	xy	1.82 ± 0.23	cm
d_{16}	cavum conchae height (tragus)	distance	xy	1.7 ± 0.21	cm
d_{17}	cymba conchae width	distance	xy	1.46 ± 0.25	cm
d_{18}	fossa triangularis height	distance	xy	1.33 ± 0.29	cm
d_{19}	fossa triangularis width	distance	xy	0.96 ± 0.21	cm
d_{20}	fossa triangularis width (inferior)	distance	xy	0.91 ± 0.16	cm
d_{21}	fossa triangularis width (superior)	distance	xy	0.78 ± 0.14	cm
θ_1	pinna rotation angle	angle	xy	9.74 ± 4.79	°
θ_2	pinna flare angle	angle	xz	31.85 ± 7.08	°
θ_3	pinna upper roll	angle	yz	28.5 ± 5.88	°
r_1	cavum conchae height	angle	xy	206.19 ± 6.37	°
r_2	cymba conchae height	angle	xy	35.39 ± 10.13	°
r_3	cavum conchae width	angle	xy	95.82 ± 10.57	°
r_4	fossa height	angle	xy	15.69 ± 9.2	°
r_7	intertragal incisure	angle	xy	136.85 ± 11.01	°
r_{11}	cavum conchae centroid	angle	xy	113.95 ± 16.82	°
r_{12}	cymba conchae centroid	angle	xy	52.4 ± 9.72	°
r_{13}	fossa triangularis centroid	angle	xy	27.31 ± 7.94	°
r_{14}	cavum conchae width (inferior)	angle	xy	117.54 ± 11.49	°
r_{15}	cavum conchae width (superior)	angle	xy	72.18 ± 9.05	°
r_{16}	cavum conchae height (tragus)	angle	xy	49.92 ± 8.25	°
r_{17}	cymba conchae width	angle	xy	144.9 ± 7.13	°
r_{18}	fossa triangularis height	angle	xy	176.07 ± 12.84	°
r_{19}	fossa triangularis width	angle	xy	125.7 ± 6.35	°
r_{20}	fossa triangularis width (inferior)	angle	xy	102.57 ± 5.34	°
r_{21}	fossa triangularis width (superior)	angle	xy	78.04 ± 7.05	°
a_1	cavum concha area	area	xy	1.62 ± 0.35	cm^2
a_2	cymba concha area	area	xy	0.62 ± 0.17	cm^2
a_3	fossa triangularis area	area	xy	0.84 ± 0.26	cm^2
v_1	cavum concha volume	volume	xyz	2.22 ± 0.6	cm^3
v_2	cymba concha volume	volume	xyz	0.61 ± 0.25	cm^3
v_3	fossa triangularis volume	volume	xyz	0.54 ± 0.23	cm^3
h_1	cavum concha depth	depth	z	2.44 ± 0.32	cm
h_2	cymba concha depth	depth	z	1.97 ± 0.32	cm
h_3	fossa triangularis depth	depth	z	1.34 ± 0.27	cm