



Title:

Prototyping the Complex Biological form of the Beetle *Deltochilum Lobipes* via 2D Geometric Morphometrics Landmarks and Descriptive Geometry for 3D Printing

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Introduction:

In this paper, we present research carried out in the Morphometrics Laboratory, Institute of Ecology, in Xalapa, Veracruz, Mexico, which consisted of creating a new method that links geometric morphometrics techniques and descriptive geometry, to find, through the coordinates "x", "y" and "z", the morphological points that define a 3D model of biological form of a beetle.

In geometric morphometrics, each morphological point or Landmark defines the numerical values of the coordinates "x" and "y" in a Cartesian space that contains any biological form, and in descriptive geometry, the geometry of any biological form is delimited by the points in space which project in the orthogonal projection.

In this project we worked with the beetle *Deltochilum Lobipes* that belongs to the *Scarabaeidae* family. We made two prototypes in 3D printing, from the 2D coordinates of morphological points which were obtained through the tpsDig2 (Rohlf 2008) program. This research documents evidence that supports the hypothesis of our project: "the quantitative descriptors of shape and size in 2D, contribute in the modeling of complex geometric structures in 3D". Our new method reconstructs "x", "y" and "z" coordinates of each point cross-references in a collection of five orthogonal images, most of each contains the same point. The collection of 3d points is then used to build a surface, a mesh, a solid, and finally a rendered 3D model for visualization and 3D printing for building a prototype.

Main Sections:

The beetle *Deltochilum Lobipes* is a good example of a very complex biological form (Fig.1 (a)). There are three body regions: head, thorax and abdomen. There are two pairs of wings, the hind wings and the elytra, and six legs. We separated the beetle in fifteen parts (Fig.1 (b)). Most parts range in size from 6 to 15 mm long, except the two wings measuring 30 mm long.



Fig. 1: (a) The beetle, and (b) Sixteen parts of the *D. lobipes* beetle.

Digital images:

We used five photos taken from above, front, back, right side and the left side to study the parts of the beetle. For the orthogonal pictures, the camera, was placed on a support (Fig.2 (a)), we designed and 3D printed: a holder (Fig.2 (b)) with a height of 10 cm, to place the beetle parts since they are very small, and a palette (Fig. 2 (c)) 18 mm wide to mark the distance between the camera and the parts, to maintain the same scale in all the photos. Testing our system with a 3D printed cube helped to assess scale accuracy across the five images.

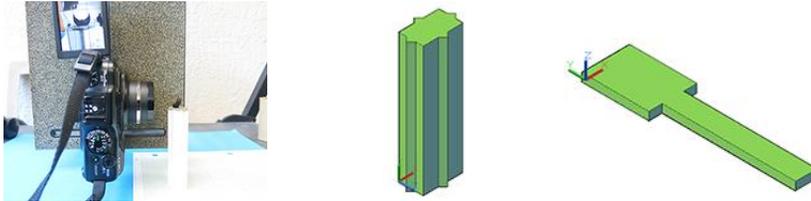


Fig. 2: (a) Camera on a holder, (b) Stand, and (c) Palette.

Procedure to reconstruct 3D coordinates from 2D coordinates in five orthogonal images:

We will explain, taking as example the elytra, the method we followed to find the numerical values of the morphological points, that is, the coordinates "x", "y" and "z" of the points in space, which from the perspective of geometric morphometrics we registered in a 2D plane.

First, an orthogonal projection was simulated in a graphics editor (in this case we used Photoshop CS6), where, four lines with 45° angle were traced to indicate the change of planes in the orthogonal projection, we will call them axes, and were placed in each of the views, the five photographs taken from the elytra.

The points that define the contour, the position of the protrusions and the curvatures of the elytra (Fig.3), were tagged with colored dots, cross-referenced by numbers in different photographs. We marked 91 points in the top view, 43 points in the front view, 55 points in the back view, 52 points in the right side view and 50 points in the left side view. This composite of five images was saved as a JPG file for the next step.

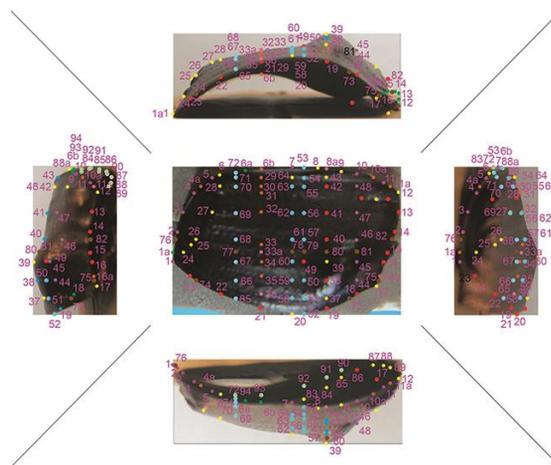


Fig. 3: Marking points in the orthogonal projection.

The mosaic of five orthogonal images was used to register “x” and “y” coordinates of all the points in each of the planes with the program tpsDig2. The tpsDig2 program creates a text file contains the numeric values of the coordinates “x” and “y” of each point, considering the origin 0,0 in the lower left side. For simplicity, we illustrate the numerical values of the axes and solely the points of one of the curves of elytra in Tab.1. In a complex biological object like this beetle, it requires a very careful protocol to keep track of points, curves and surfaces to localize spatial correspondences of each point in the five planes, with the goal to find the numerical value of the coordinate “z”.

Axes				Top view		Front and back view		Right and left side view	
	X	Y	Points	X	Y	X	Y	X	Y
1	550	1281	19	1239	680	1240	1636	193	680
2	1611	1284	37	1238	721	1237	1702	128	720
3	1612	616	38	1240	790	1239	1728	103	789
4	548	616	39	1239	863	1238	1743	88	861
			40	1239	948	1240	196	130	949
			41	1238	1051	1240	211	141	1050
			42	1238	1152	1239	238	171	1151
			43	1237	1188	1240	251	182	1187
			8a	1239	1221	1237	301	228	1221

Tab. 1: Numerical values of the axes and numerical values for one curve of the elytra.

The numerical value of the coordinate “z” was found by subtracting, considering the highest numerical value, the numerical values of the coordinates “y” among the axes and the front and back views, and the numerical values of the coordinates “x” among the axes and the left and right side views. These operations were made in Excel. At the end, it is possible to concatenate the three numerical values of the coordinates “x”, “y” and “z” of each point. All these concatenated numbers were saved from Excel in a CVS format (Tab.2).

Axis				Top View		Front view		Left view		Concatenation
	X	Y	Points	X	Y	X	Z	Z	Y	
1	550	1283	19	1239	682	1239	355	355	682	1239,682,355
2	1612	1283	37	1239	721	1239	421	421	721	1239,721,421
3	1612	616	38	1239	790	1239	446	446	790	1239,790,446
4	550	616	39	1239	861	1239	461	461	861	1239,861,461
			40	1239	949	1239	420	420	949	1239,949,420
			41	1239	1051	1239	407	407	1051	1239,1051,407
			42	1239	1153	1239	379	379	1153	1239,1153,379
			43	1239	1186	1239	367	367	1186	1239,1186,367
			8a	1239	1221	1239	323	323	1221	1239,1221,323

Tab. 2: Numerical values of the axes and one curve of the elytra.

Building a surface, a mesh, a solid and finally a rendered 3D model for visualization and 3D printing:

In the second part of the procedure the elytra was modeled (AutoCAD 2013 program). First, the three concatenated numerical values of the 3D points were imported to an AutoCAD file.

The points were joined by means of lines in space (Fig.4), the meshes were modeled by means of surfaces, the thickness of elytra was delimited by copying and scaling the meshes and all meshes were joined to form the solid (Fig.5).

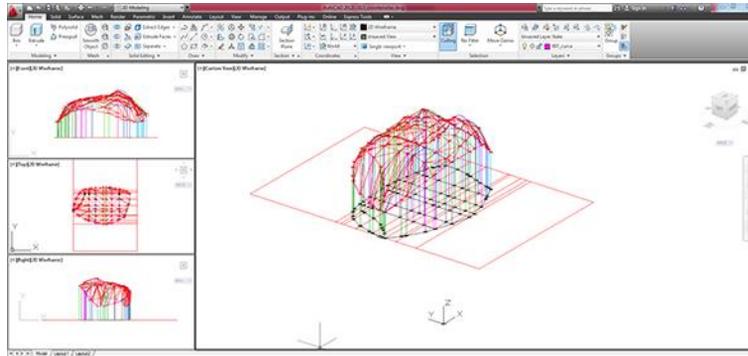


Fig. 4: Elytra, via points in a wireframe.

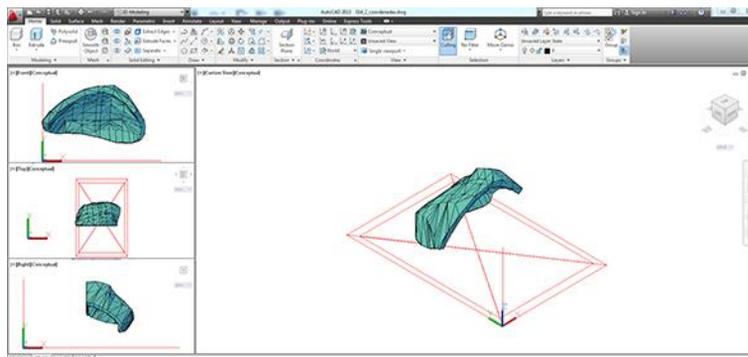


Fig. 5: Elytra, as solid.

The elytra was escalated to measure 60 mm long, considering the largest of the beetle, and also the largest print area of the 3D printer. The STL file was submitted to the MakerBot software for the preparation of the x3g file for 3D printing and comparison of the prototype with the original form (Fig.6).



Fig. 6: Comparison of the 3D prototype with the elytra shape.

The sixteen parts of the beetle were printing following the same procedure from digital images, the mosaic of five orthogonal images to register “x” and “y” coordinates of all the points, the building of surfaces, meshes, the 3D models. Finally, all parts were digitally joined in AutoCAD for 3D visualization (Fig.7), 3D printing, and assembling the two prototypes (Fig.8)

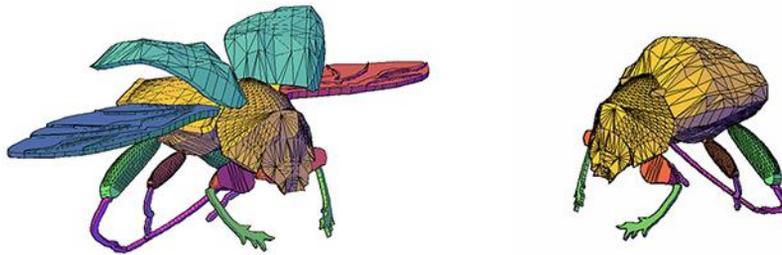


Fig. 7: The two beetles modeled in AutoCAD.

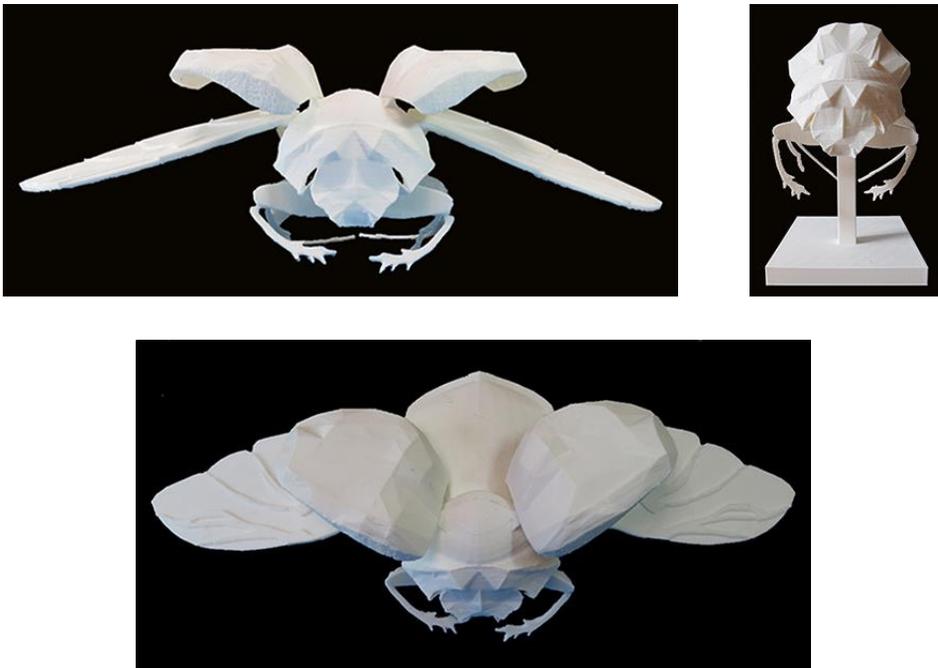


Fig. 8: 3D printing of the two prototypes.

Contribution

Techniques of geometric morphometrics and descriptive geometry, used their own procedure to find the shape and size of the biological form in a plane (2D) and in space (3D). In this research, we demonstrate, that quantitative description of the shape and size of the beetle that were registered through the geometric morphometric 2D landmarks contributed in the modeling of 3D prototype by means of descriptive geometry.

This research not only contributes in the scientific and educational field in the area of Biology, but also, contributes to the areas of Design, Architecture, Engineering and Robotics, because with this method, will be developed complex biological forms that can be used to perform structural and biomechanical studies.

Conclusions:

To date, there has been no joint investigations between geometric morphometrics and descriptive geometry methods to find the points in a three-dimensional space to print 3D prototypes. The method described in this document will help researchers and students to create prototypes to study the morphological and geometrical properties of complex biological forms without 3D scanner or 3D digitizers.

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References:

- [1] Rohlf, F. J.: TpsDig, version 2.12, Stony Brooks Department of Ecology and Evolution, State University of e work at Stony Brooks. 2008. Available at <http://life.bio.sunysb.edu/morph/>
- [2] Rohl, F. J.: Geometric morphometrics simplified: Trends In Ecology and Evolution, USA, <http://dx.doi.org/10.1016/j.tree.2004.08.005>
- [3] Zelditch, Miriam; Swiderski, Donald L; Sheets, H. Davis; Fink, William.: Geometric Morphometrics for Biologist: A Primer, Elsevier Academic Press, USA, 2004. <http://dx.doi.org/10.1016/B978-012778460-1/50007-7>