



Computer-Aided Design for Two-Dimensional Simulation of the Mechanism of a Three-Dimensional Pantograph

Dina Rochman 

Universidad Autónoma Metropolitana, Cuajimalpa, drochman@cua.uam.mx

Corresponding author: Dina Rochman, drochman@cua.uam.mx

Abstract. In this document, we present the two-dimensional simulation of a three-dimensional pantograph to find the numerical values of the x and y coordinates of each point of the curves of the parts of insects and mollusks. The simulation is carried out in the Adobe Animate 2022™ program using the ActionScript 3.0 object-oriented language. In several tests that we carry out, we verify that the operation of the computer program that we designed is correct since the numerical values of the x and y coordinates of each point coincide with the numerical values of the x and y coordinates of each point that we traced in the AutoCAD™ program. By marking the time in the simulation, it is possible to predict the total time that the three-dimensional pantograph would take to provide the coordinates of each point of the exoskeleton curves.

Keywords: Three-dimensional Pantograph. Two-dimensional simulation. The numerical value of the x and y coordinates.

DOI: <https://doi.org/10.14733/cadaps.2023.248-260>

1 INTRODUCTION

Insects and mollusks are part of the culture and ecosystem around the world. Biologists study them using the methods of geometric morphometry [7] or mark-break [8] to analyze their growth and the morphological changes that both insects and mollusks have undergone due to climate change.

Using these two methods involves a lot of time and effort for biologists because the work is initially done manually by marking the landmarks. They then use computer programs for their analysis, description, and evaluation.

The analysis of these two methods led us to think that the curves of small-scale animal parts can be found in another way instead of using the numerical values of geometric morphometry. Therefore, we propose to use another method based on the fundamentals of the descriptive geometry of the projections of points in space in the orthogonal projection.

This method consists of finding the numerical values of the reference points, the x and y coordinates, and the curves of the parts of insects and mollusks through a three-dimensional pantograph that we design, print, and assemble.

Geometrically our three-dimensional pantograph is based on Gaspard Monge's method of representation [9]. Having the following parts: (1) a table with wheels that moves back and forth on the z -axis through a band; (2) a rectangular base on a rail that moves right and left on the x -axis through an Acme threaded rod. On this base are the pointer and the tip of the pencil. And (3) two threaded Acme rods to move the rail up and down on the y -axis (Figure 1).

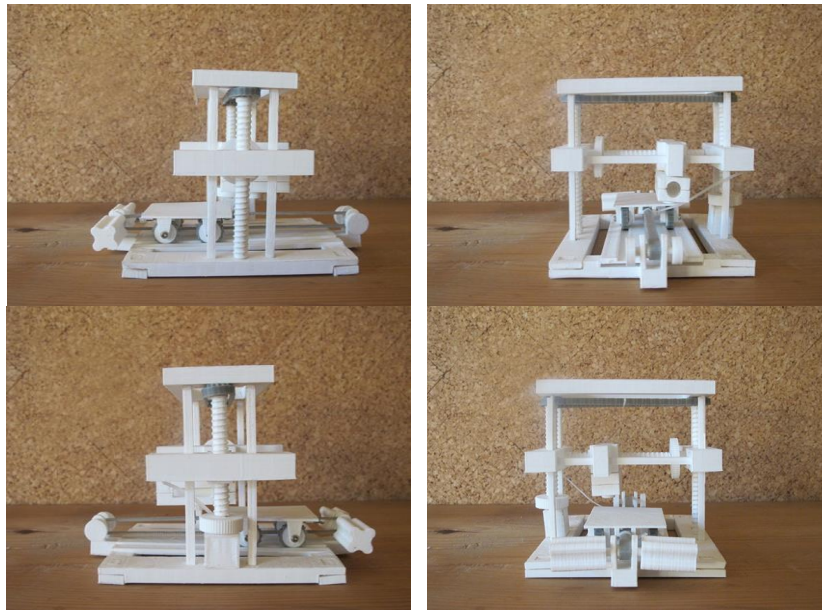


Figure 1. Photographs of the three-dimensional pantograph prototype.

Once we solved the movements of the physical prototype, we set ourselves the task of creating a computer program to find the numerical values of the x and y coordinates of the reference points of the curves of the exoskeleton according to the movements of the pantograph.

We perform the two-dimensional simulation using the ActionScript 3 object-oriented language to check the operation of the three-dimensional pantograph mechanism and verify that the numerical values of the x and y coordinates of each of the points of each of the curves are correct.

It is worth mentioning that we work directly with biologists. To analyze the morphology of mollusks or insects, biologists need the numerical values of the x and y coordinates. The data used for the analysis correspond to a set of landmarks representative of a shape. A milestone (or «landmark») corresponds to a point in space that has a name -such as the cephalometric points or others defined by the operator- and Cartesian coordinates (x, y) in two-dimensional forms, and (x, y, z) in three-dimensional, which are those that describe their position in the space [11].

The objective of the three-dimensional pantograph simulation is to describe a new method to find the numerical values of the x and y coordinates of the parts of mollusks and insects to carry out their morphological analysis.

This article has the following sections: Section 2, describes the methodology we followed; Section 3 explains the design implementation. Section 4 explains how the computer program

operates. Section 5 lists the results and, finally, Section 6 presents the conclusions. All the figures in this document are original and created by the author that works at the Metropolitan Autonomous University Campus Cuajimalpa in Mexico City.

2 METHODOLOGY

The methodology used to perform the two-dimensional simulation according to the movements of the three-dimensional pantograph consists of three parts.

In the first part, we define the operation of the three-dimensional pantograph from the geometric point of view (Figure 2).

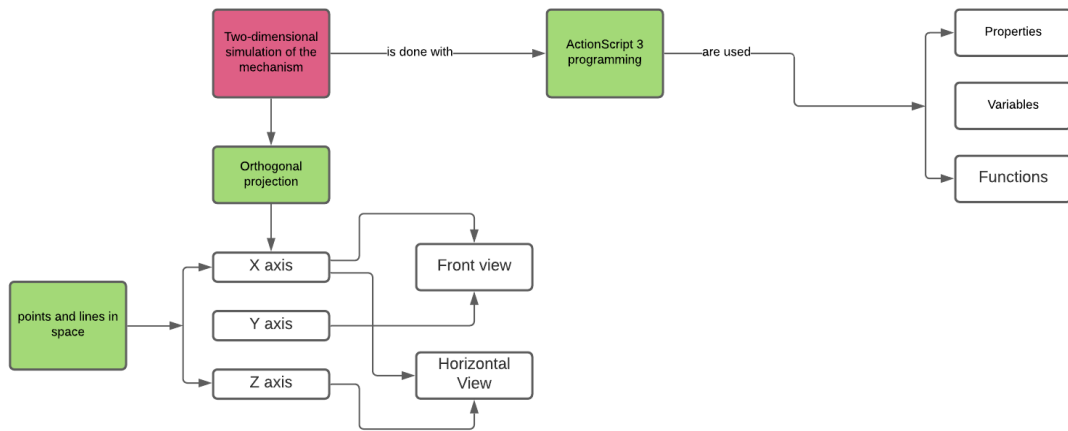


Figure 2. The first part of the methodology.

In the second part, the algorithm was defined (Figure 3).

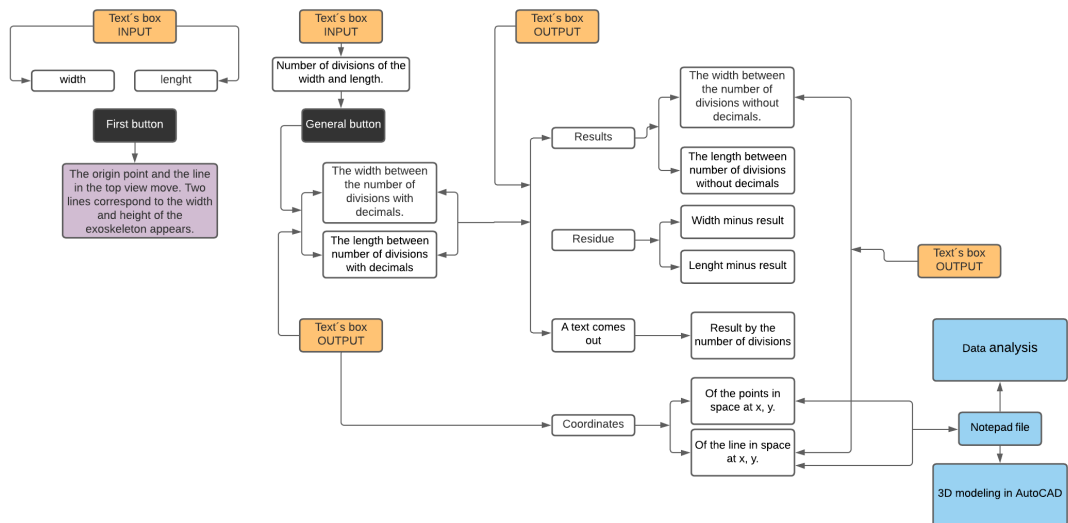


Figure 3. Algorithm.

And in the third part, the graphic user interface was defined (Figure 4).

On the left side of the graphical interface will be the animation. On the right side of the graphical interface, there are three buttons and several text boxes for input and output data.

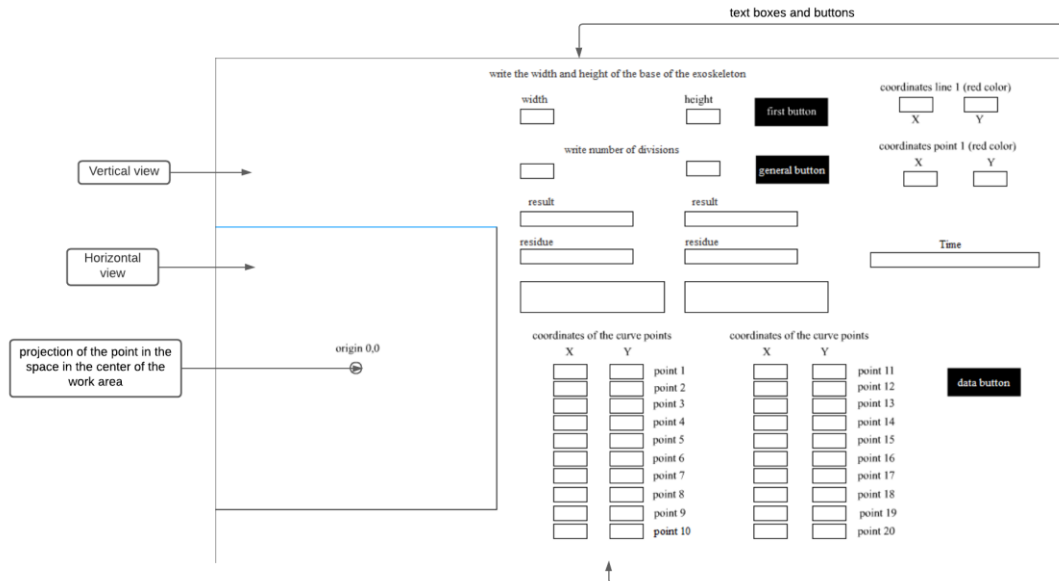


Figure 4. Graphical user interface.

3 DESIGN IMPLEMENTATIONS

In the computer program, the input data is the width and length of the exoskeleton and the number of parts it is divided into vertically and horizontally to create a grid.

```
inputAncho = Number(anchoEntrada.text);
```

```
inputLargo = Number(largoEntrada.text);
```

The program processes and stores the numerical values of the number of divisions and the remainder. The remainder is the numerical value after the decimal point.

```
function anchoLargoResultado(e: MouseEvent) {
    resultadoAncho.text=String(Number(anchoEntrada.text)/Number(anchoDivisiones.text);
    var numAncho: Number = (Number(resultadoAncho.text));
    var valorAncho: Number = Number(int(numAncho));
    resultadoAnchoSinDecimales.text = ("distancia divisiones:" + valorAncho);
```

With these numerical values, we program the animation to recreate the two-dimensional simulation of the three-dimensional pantograph, where the red line moves from bottom to top; the red point moves to the right many times as the number of divisions. Each time the pointer touches a point on the exoskeleton curve, it simulates the points marked on the paper.

An Array is used in programming to show all the points that simulate the trace on the paper.

```
var circulos: Array = new Array(circulo1, circulo2, circulo3, circulo4, circulo5, circulo6,
circulo7, circulo8, circulo9, circulo10, circulo11, circulo12, circulo13);
for each(var circulo in circulos) {
    if (nuevaLinea1.hitTestObject(circulo)) {
        nuevaLinea1.y == circulo.y;
```

```

var circuloVerde: Sprite = new Sprite();
circuloVerde.graphics.beginFill(0x605858);
circuloVerde.graphics.drawCircle(nuevaLinea1.x, (nuevaLinea1.y - 150), 5);
circuloVerde.graphics.endFill();
addChild(circuloVerde);
removeEventListener(Event.ENTER_FRAME, bajarLineaY);

```

Once the animation ends, we have the numerical values of the coordinates x and y of each of the points of the exoskeleton curve.

We finish the programming with the file reference. The numerical values of the x and y coordinates of each point of the exoskeleton curve are in the notepad.

```

fileRef = new FileReference;
fileRef.save(textToSave, "matematicas5_4_5");

```

In programming, we consider a timer. The Timer indicates the time it will take for the three-dimensional pantograph to complete the journey.

```

var tiempo = 0;
var timer: Timer = new Timer(1000, 200);
timer.addEventListener(TimerEvent.TIMER, contarTiempo);
timer.start();
function contarTiempo(e: TimerEvent) {
    tiempo++;
    cajaTiempo.text = tiempo.toString();
}

```

4 COMPUTER PROGRAM OPERATION.

In the Adobe Animate 2022™ program, both animation and programming were performed, using the object-oriented ActionScript 3.0 language to find the numerical values of each point curve.

The computer program works as follows:

- (1) We write the width and length of the base of the exoskeleton, 300 units wide and 200 units long, and the number of divisions, 12 in the width and 6 in the length.
- (2) The red line and the red point are in the coordinates 0,0. When is pressed the "First button", they change their position to the following coordinates: point x = 100, y = 650, and line x = 100, y = 300. The numerical values can see in the corresponding boxes. Two black lines appear in the horizontal view of the orthogonal projection, indicating the width and length of the exoskeleton.
- (3) When the "General button" is pressed, the result and residue of each of the axes are seen in each of the boxes. The distance value divisions by the number of divisions also are seen. Time begins to run.
- (4) The "General button" is pressed again 12 times for the width and 6 times for the length. The red line and point that simulate the pointer move to the coordinate corresponding to each division. At the same time, it can see the gridlines in the horizontal view of the orthogonal projection. The exoskeleton curve appears with the points indicating the 12 divisions in the vertical view of the orthogonal projection.
- (5) The animation begins. The red line moves from bottom to top, the red point moves to the right as many times as the number of divisions. Each time the pointer touches a point on the exoskeleton curve, it simulates the points marked on the paper.
- (6) Once the animation ends, the numerical values of the coordinates x and y of each of the points appear in the boxes of the coordinates of the curve point (Figure 5).

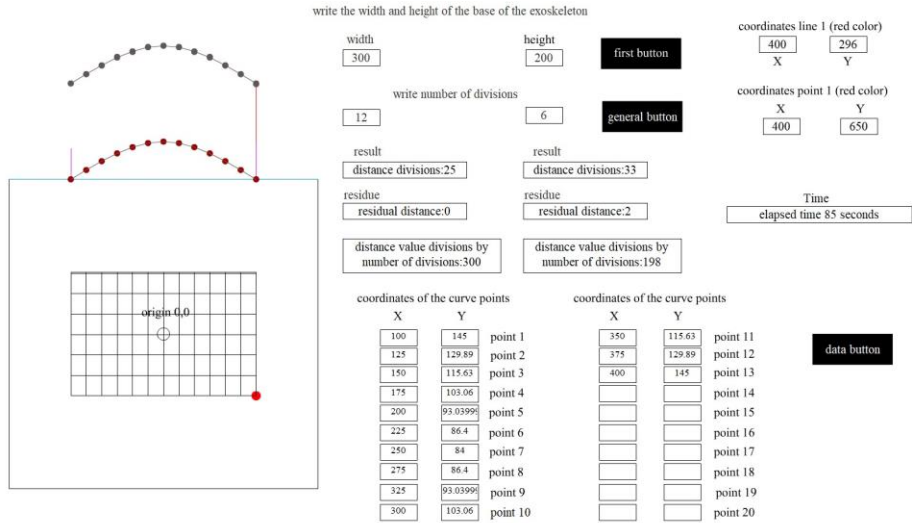


Figure 5. Numerical values of the coordinates x and y of each of the points.

- (7) By pressing the "Data button" the numerical values of the coordinates x and y of each of the points are automatically saved in the notepad. Two values are left after the decimal point (Figure 6).



Figure 6. Numerical values of the coordinates x and y of each of the points

- (8) The numerical values of the coordinates x and y are copied and passed to the AutoCAD™ computer program to trace the curve. The points on the curve are backward because the origin of the Adobe Animate 2022™ computer program is at the top, and in AutoCAD™, it is at the bottom. So, the points are rotated 180° (Fig 7) to position them correctly in the isometric projection (Fig 8).

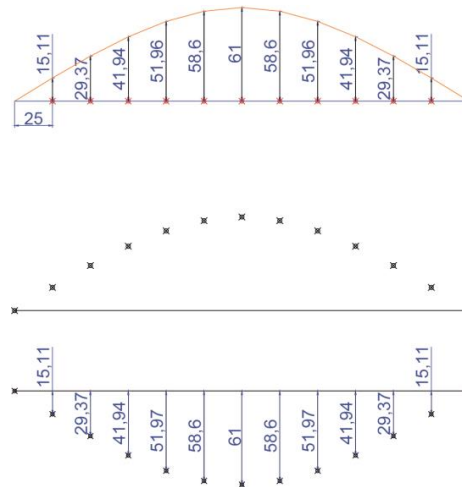


Figure 7. (a) Trace and distances of the curve, (b) Curve points rotated and (c) Comparison of distances.

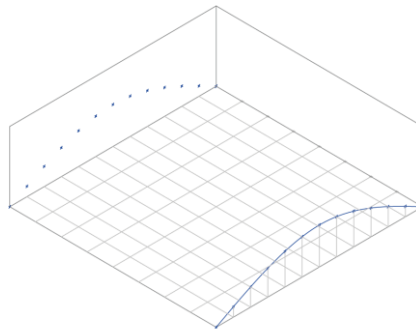


Figure 8. Outline of the curve in the isometric projection.

5 RESULTS

In the literature that we reviewed, we found several writings related to the topic that we deal with in our research which explain the method they use to reproduce the biological forms of insects and mollusks. The Plum and Labonte [3] method consists of a scanner and a graphical user interface, which allows the automated generation of extended depth-of-field images from multiple perspectives. The images are processed with photogrammetry software to create high-quality textured 3D models.

Bernhard Ströbel, et al [10] explains that they use a digitizing nailed insects digitization device for pinned insects, where images are computed from an image stack using a novel calibrated scaling algorithm that meets the requirements of the pinhole camera model (a single central perspective).

Jia Qian, et. al [4] explain that his method has an approach based on structured lighting capable of offering three-dimensional images with a large field of view.

The method that Juan Carlos Plaza Archundia presents in his thesis [2] consists of stereophotogrammetry. In this method, a pair of cameras arranged in parallel is used, and together with analytical geometry, it is possible to deduce the depth of objects.

Since 2015 we have been working on the geometric reproduction of the biological forms of insects and mollusks. We first use the method of geometric morphometry, where we use photographs to mark the reference points in a two-dimensional environment (Rochman, D. et al) [5].

Sometime later, we designed, printed, and assembled a prototype consisting of a table to place the exoskeleton, a template to hold saw blades that work as rails, three prism-shaped bases, an L-shaped piece to hold a pencil point, and a pointer [6].

This prototype led us to the design of the three-dimensional pantograph that we present to find the numerical values of the x and y coordinates with greater accuracy to use in statistical studies and perform 3D printing.

The three-dimensional pantograph exposed is for the study of insects and mollusks. Geometrically, we use Gaspard Monge's method of representation in its design [9] (Figure 9).

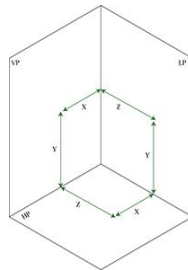


Figure 9. Gaspard Monge's method of representation.

In its solution, we consider the synthesis and simulation stages. In the synthesis stage, we focus on the functionality of the mechanism, which until now is manual. The table with wheels moves back and forth on the z -axis through a band. The rectangular base with the pointer and pencil tip that is on a rail moves left and right on the x -axis using an Acme threaded rod, and the two threaded Acme rods move the rail up and down on the y -axis (Figure 10).

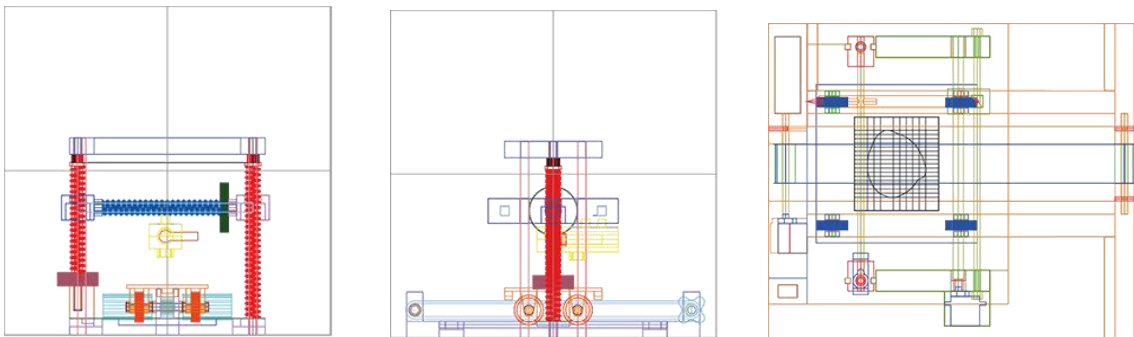


Figure 10. Side, front, and top view of the model.

In the simulation stage, we focus on finding the numerical values of the x and y coordinates of the reference points of the exoskeleton curves using a computer program we designed.

Before starting with the programming, we draw in the AutoCAD™ program a diagram of the curve that goes from point 0 to point 300 to find the height distances of the curve every 25 units. We execute the program to obtain the results in the graphical interface (Figure 11).

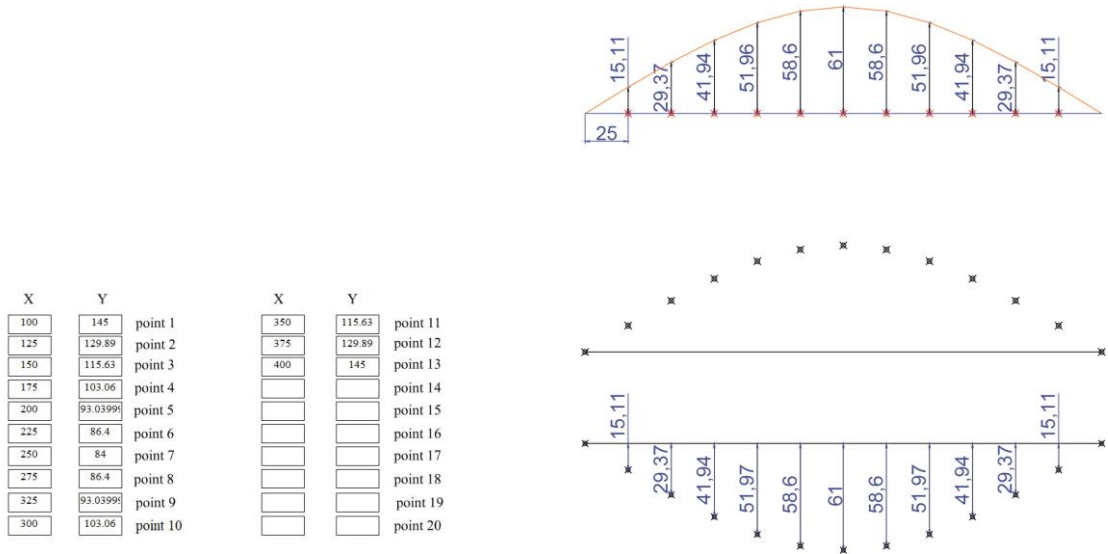


Figure 11. First trial (a) Results of the graphical interface, (b) Trace and distances of the curve, (c) Curve points rotated, and (d) Comparison of distances.

We mathematically verified the distances between the traces of the AutoCAD™ program and the results of the y coordinates of the computer program we made (Table 1).

	Y coordinate	Operations	Curve distances
point 1	145		0
point 2	129.89	145-129.89	15.11
point 3	115.63	145-115.63	29.37
point 4	103.06	145-103.06	41.94
point 5	93.03	145-93.03	51.97
point 6	86.4	145-86.4	58.6
point 7	84	145-84	61
point 8	86.4	145-86.4	58.6
point 9	93.03	145-93.03	51.97
point 10	103.06	145-103.6	41.94
point 11	115.63	145-115.63	29.37
point 12	129.89	145-129.89	15.11
point 13	145		0

Table 1. Mathematical comparison of the curve distances in the first trial.

By having the traces and numerical values of various curves, we perform the tests to check the program. The second trial's total distance is 300 units with 12 divisions every 25 units (Figure 12). The total distance of the third trial is 400 units with 18 divisions every 22 units and a remainder of 4 units (Figure 13).

We mathematically verified the distances between the traces of the AutoCAD™ program and the results of the y coordinates of the computer program we made (Table 2, and Table 3).

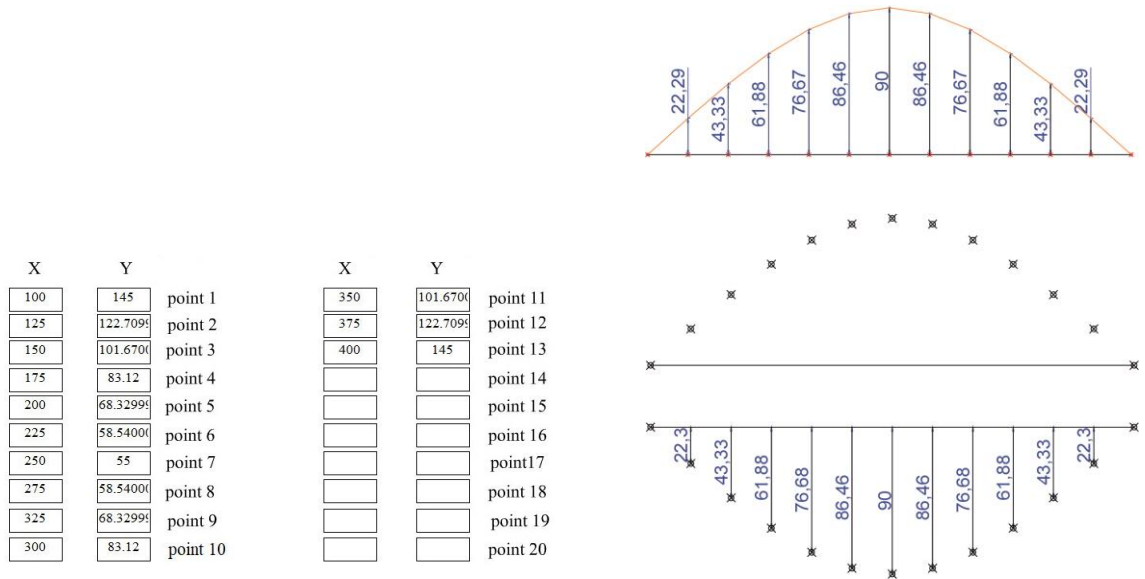


Figure 12. Second trial (a) Results of the graphical interface, (b) Trace and distances of the curve, (c) Curve points rotated, and (d) Comparison of distances.

	Y coordinate	Operations	Curve distances
point 1	145		0
point 2	122.7	145-122.7	22.3
point 3	101.67	145-101.67	43.33
point 4	83.12	145-83.12	61.88
point 5	68.32	145-62.32	76.68
point 6	58.54	145-58.54	86.46
point 7	55	145-55	90
point 8	58.54	145-58.54	86.46
point 9	68.32	145-62.32	76.68
point 10	83.12	145-83.12	61.88
point 11	101.67	145-101.67	43.33
point 12	122.7	145-122.7	22.3
point 13	145		0

Table 2. Mathematical comparison of the curve distances in the second trial.

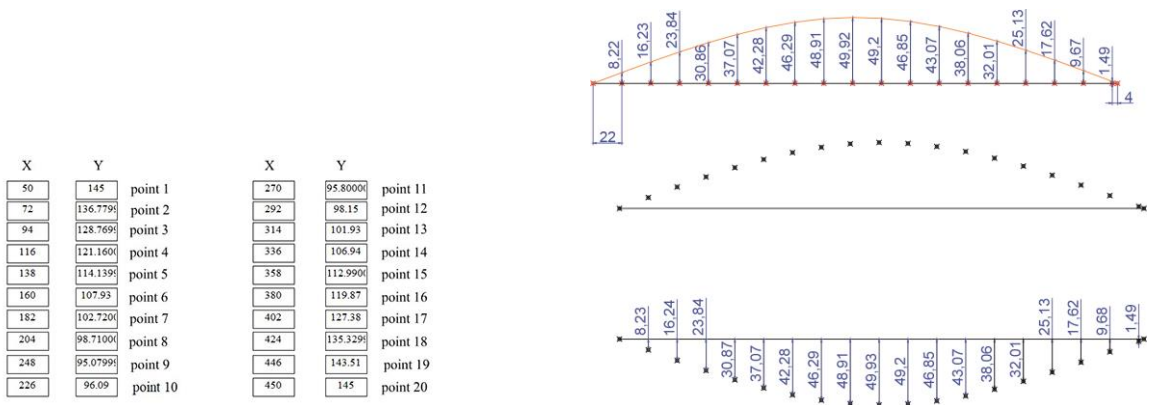


Figure 13. Third trial (a) Results of the graphical interface, (b) Trace and distances of the curve, (c) Curve points rotated, and (d) Comparison of distances.

	Y coordinate	Operations	Curve distances
point 1	145		0
point 2	136.77	145-136.77	8.23
point 3	128.76	145-128.76	16.24
point 4	121.16	145-121.16	23.84
point 5	114.13	145-114.13	30.87
point 6	107.93	145-107.93	37.07
point 7	102.72	145-102.72	42.28
point 8	98.71	145-136.77	46.29
point 9	95.07	145-98.71	49.93
point 10	96.09	145-96.09	48.91
point 11	95.8	145-95.8	49.2
point 12	98.15	145-98.15	46.85
point 13	101.93	145-101.93	43.07
point 14	106.94	145-106.94	38.06
point 15	112.99	145-112.99	32.01
point 16	119.87	145-119.87	25.13
point 17	127.38	145-127.38	17.62
point 18	135.32	145-135.32	9.68
point 19	143.51	145-143.51	1.49
point 20	145		0

Table 3. Mathematical comparison of the curve distances in the third trial.

The time the program takes to recreate each of the curves is 90 seconds in the first trial, 78 seconds in the second trial, and 138 seconds in the third trial. If the length divisions of the exoskeleton were 7, 10, or 18, the total time would be: (Table 4).

seconds	Divisions in length	Total time in seconds	Total time in minutes
90	7	630	10.5
78	7	546	9.1
138	7	966	16.1
90	10	900	15
78	10	780	13
138	10	1380	23
90	18	1620	27
78	18	1404	23.4
138	18	2484	41.4

Table 4. Estimated total time.

The results found in the three tests show that the numerical values of the x and y coordinate that the computer program throws coincide with the points of the curves in the AutoCAD™ program. The objective of our study was fulfilled since the method works correctly.

The methods and technologies that the authors mention in their writings serve to reproduce digitally or 3D printing the biological forms of insects or mollusks so that biologists can use them for analysis or use as a collection for a museum. They handle photography as the main element.

The three-dimensional pantograph is a new technology that we propose for use by biologists or other people interested in the subject of biological forms. Its operation is friendly to biologists. Since the biologist would only have to place the exoskeleton on the table, write the data, the total width and length, and the number of divisions on the x and y axes. Once the program finished executing, the biologist or technician would have the results of the numerical values of the x and y coordinates automatically in the notepad to carry out the corresponding studies. The description of measurable morphological characters of size and shape requires the numerical language provided by linear measurements and Cartesian coordinates, and the comparison can only be qualified by a statistical procedure [1].

Our method has three advantages, the biologist will be able to carry out the entire process in his laboratory they will not need to hire other people or other places. Work directly with the physical parts of the specimens to capture the Cartesian coordinates expressed as landmarks, semi-landmarks, or contours, and they will know how long it would take for the three-dimensional pantograph to do all the work.

With these data, it is possible to predict how long the three-dimensional pantograph might take to perform other tasks or to re-run the program with new data, for example, by changing the number of divisions.

6 CONCLUSIONS

Since we verify that the computer program we designed works correctly and that it throws us time, we conclude that we will be able to optimize the mechanism of the CNC three-dimensional pantograph.

The work that remains is the modeling and 3D printing of the exoskeleton so that biologists can describe, understand, and predict changes in nature. And geometers can analyze the structure of insects and mollusks.

ACKNOWLEDGMENTS

I want to express my gratitude to Alfredo Almaraz for his support in the realization of the 3D printing of the model for this research.

Dina Rochman, <http://orcid.org/0000-0001-8902-3513>

REFERENCES

- [1] De Luna, E.: Integrating morphometric and phylogenetic analyses: from phenetic systematics to phylogenetic morphometrics, *Acta botánica Mexicana*, num.127, México, 2020, <https://doi.org/10.21829/abm127.2020.1640>
- [2] Plaza, J.C.: Morfometría 3D de especies ícticas del arrecife Santiaguito, PNSV, Veracruz, Bachelor's degree, Thesis, National Autonomous University of Mexico, Zaragoza Faculty of Studies, https://www.zaragoza.unam.mx/wpcontent/Portal2015/Licenciaturas/biologia/tesis/tesis_plaza_archundia.pdf
- [3] Plum, F.; Labonte, D.: scAnt-and open-source platform for the creation of 3D models of arthropods (and other small objects), *PeerJ*, doi:10.7717/peerj.11155 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8048404/>
- [4] Qian, J.; Dang, Sh.; Wang, Z.; Zhou, X.; Dan, D.; Yao, B.; Tong, Y.; Yang, H.; Lu, Y.; Chen, Y.; Yang, X.; Bai, M.; Lei, M.: Large-scale 3D imaging of insects with natural color optics, *Express* 27(4), 2019, 4845-4857, <https://doi.org/10.1364/OE.27.004845> <https://opg.optica.org/oe/fulltext.cfm?uri=oe-27-4-4845&id=404866>
- [5] Rochman, D.; De Luna, E.: Prototyping the complex biological form of the beetle *Deltochilum Lobipes* via 2D geometric morphometrics landmarks and descriptive geometry for 3D printing, *Computer-Aided Design & Applications*, 14(1), 2017, 107-116. <https://doi.org/10.1080/16864360.2016.1199761>
- [6] Rochman, D.: Design of a Prototype to Delineate the Curves of Exoskeletons to Produce 3D Models, *Computer-Aided Design & Applications*, 19(3), 2020, 575-586. <https://doi.org/10.14733/cadaps.2022.575-586>
- [7] Rohlf, F. J.: Geometric morphometrics simplified: Trends in Ecology and Evolution, USA, <https://doi.org/10.1016/j.tree.2004.08.005>
- [8] Searcy, R.; Lugo, J.; Beltrán, C.: Periodicity of internal growth ring deposition in the Pismo clam (*Tivela stultorum*) from Playa San Ramon, BC, Mexico, *Ciencias marinas*, México, 1989. <http://doi.org/10.7773/cm.v15i3.655>
- [9] Schreck, K.: Monge's Legacy of descriptive and differential geometry, Docent Press, Boston, Massachusetts, USA, 2016 Eaton, J. A.: Layered Manufacturing Methods for Reconstructing Bone Structures, Ph.D. Thesis, University of Minnesota, Twin Cities, MN, 1998.
- [10] Ströbel, B.; Schmelzle, S.; Blüthgen, N.; Heethoff, M.: An automated device for the digitization and 3D modeling of insects, combining extended depth of field and all side multi-view imaging, *Zookeys* 759:1-27, <https://doi.org/10.3897/zookeys.759.24584>, <https://zookeys.pensoft.net/article/24584/>
- [11] Toro, I.M.V.; Manriquez, S.G.; Suazo, G.I.: Morfometría geométrica y el estudio de las formas de las formas biológicas: de la morfometría descriptiva a la morfología cuantitativa, *Int. J. Morphol*, 28 (4): 977-990, 2010, <https://repositorio.uchile.cl/handle/2250/129328>