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Article

Design and CAD modeling of the mechanical base of an anthropomorphic robot arm, integrating technical analysis, 2D/3D drawing, assembly and animation, for educational purposes

Diseño y modelado CAD de la base mecánica de un robot industrial tipo brazo antropomórfico, integrando análisis técnico, dibujo 2D/3D, ensamblaje y animación, con fines educativos

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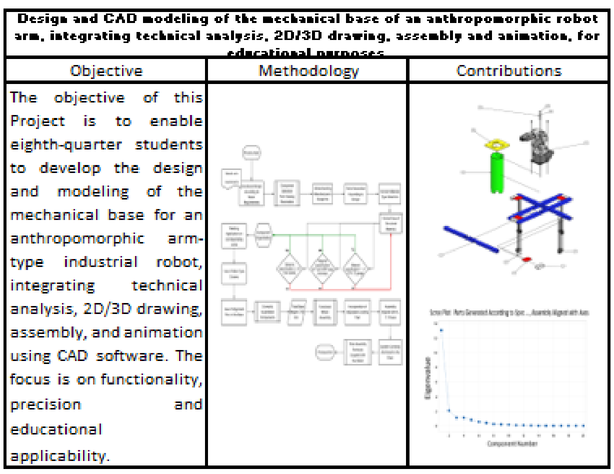
Abstract

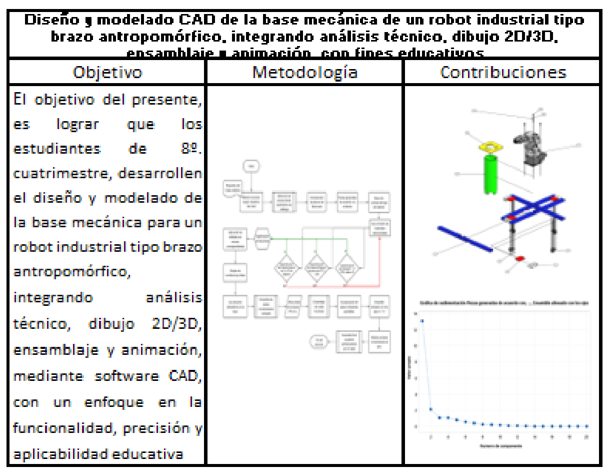
The objective of this work was to enable eighth-quarter students to develop the design and modeling of the mechanical base for anthropomorphic arm-type industrial robot, integrating technical analysis, 2D/3D drawing, assembly, and animation using CAD software, with a focus on functionality, precision, and educational applicability. The resulting matrix of components that can be integrated for subsequent analysis is presented as follows: Generated Parts, Understanding of manufacturer's drawings, and proper assembly of parts. Functional tests were performed. It was demonstrated that the development of experiences in the area of robotics has allowed participating students to improve their problem-solving skills through virtual models, visualizing their designs in three dimensions and identifying potential problems. Adjustments can save time and resources, and are proposed as future lines of research. As future lines of research, we propose evaluating various forms of work that involve the convergence of digital technologies and hardware to improve processes, simulate multidimensional physical models, and reduce costs. It is worth mentioning that this study is not without limitations, derived from the selection of analyses, therefore, it should be treated with caution.



CAD Design and Modeling, Educational Robotics, Mechatronics

Resumen

El objetivo del presente trabajo fue lograr que los estudiantes del 8° cuatrimestre, desarrollen el diseño y modelado de la base mecánica para un robot industrial de tipo brazo antropomórfico, integrando análisis técnico, dibujo 2D/3D, ensamblaje y animación, mediante software CAD, con un enfoque en la funcionalidad, precisión y aplicabilidad educativa. Como resultado se obtuvo se presenta la matriz de componentes que se pueden integrar para posteriores análisis como sigue: Piezas Generadas, Comprensión de planos del fabricante y ensamble de piezas correctamente y se realizaron las pruebas de funcionamiento. Se logró evidenciar que los desarrollos de experiencias en el área de robótica han permitido que los estudiantes participantes, mejoren su habilidad de resolución de problemas a través de modelos virtuales, visualizando sus diseños en tres dimensiones e identificando problemas potenciales, que, realizando ajustes, promueven el ahorro de tiempo y recursos. Como líneas de investigación futuras se propone evaluar diversas formas de trabajo que impliquen la convergencia entre las tecnologías digitales y el hardware, a fin de mejorar los procesos; simulando modelos físicos multidimensionales y reducir costos; cabe mencionar que el presente estudio no está exento de limitaciones, derivados de la selección de análisis, por tanto, debe ser tratado con precaución.



Diseño y modelado CAD, Robótica Educativa, Mecatrónica

Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Introduction

In the early 1990s, the concept of parametric design gained momentum, where product modeling was performed under certain geometric criteria that allowed different configurations by changing the values of some parameters. Several companies adopted this work concept and have now consolidated their position with the incorporation of associative technologies (Bodein y col., 2014)

The tools for Computer Aided Design (CAD) is constantly evolving and most branches of technology use it to increase the productivity of designers and to obtain more complex and precise elaborations every day.

In recent years CAD software, some of which is offered as a free or open surce Project, has been a key conditions for the expansión of 3D modeling and rapid prototyping.

A designer working on a system with a high-resolution screen generates various views of components and assemblies, he can also obtain three-dimensional views that can be zoomed, rotated and cut into sections, allowing customers and profesionales involved in design and manufacturing to form an idea of the product in question, facilitating all possible modifications and defect elimination before the product goes to market.

Initially CAD was introduced to assist designers in error-proofing their designs. It was also used to aid engineering analysis. Although the design process continued to be performed by hand for a long time, at certain points throughout these processes, data was entered into computer programs that analyzed and identified potential errors, and then made the necessary modifications to these designs (Fakhry y col., 2021).

In addition, it allows you tu include standardized elements in your Project, verify interactions with mechanical construction parts, and optimize the creation of shop drawings and safety factors, as well as analyze movement trajectories (Mercado-Bautista, 2020). A significant advantage lies in the analysis and optimization of designs, as it allows for increased product efficiency and error elimination without generating aditional costs for real prototypes (Lopes and Guedes, 2016)

The objective of this Project is to enable eighth-quarter students to develop the design and modeling of the mechanical base for an anthropomorphic arm-type industrial robot, integrating technical analysis, 2D/3D drawing, assembly, and animation using CAD software. The focus is on functionality, precision and educational applicability. This approach develops skills such as creativity and critical thinking to enhance their problem-solving abilities (Diago, Arnau and González-Calero, 2018; Benitti, 2012).

The first section presents a literature review, conceptual framework, and methodology, as well as a review of the work related to the design of the mechanical base for an anthropomorphic arm-type industrial robot.

The second section describes the methodology used, followed by sections on analysis of results, discussion, conclusions and limitations, as well as proposals for future research work.

Contextual Framework

From a practical perspective, robots are machines that function by emulating human processes. The robot design process generally requires a balance between functionality structure, and aesthetics, as well as other associated interests (Yang and col., 2022.)

Robots can be classified by configuration as a) Cartesian, b) Cylindrical, c) Spherical, d) Angular, e) SCARA and f) Parallel (Barrientos y col., 2007). Articulated robots have an arm composed of three rigid members connected by two rotating joints. The arm is mounted on a rotating base. Thus, engineers prioritize functional characteirstics, that is, they are responsable for formulating the technical specifications that govern the manufacturing process, product performance, and its overall shape.

To extend the lifespan of robots and facilitate their maintainability, the implementation of a mechanical base that improves stability, strength, and precisión has become popular; allowing a wide range of movements and/or more complex movements, allowing the robot to perform different tasks, in addition to providing support and locomotion capabilities to interact with different environments or increasing energy efficiency.

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Mechanical bases can be fixed or mobile

Depending on the movement method, mobile robots fall into two main categories: wheeled robots and legged robots. Legged robots are classified according to the number of legs they use for movement and the degrees of freedom of each one. Therefore, perhaps the most valuable characteristic of an articulated robot is its mechanical flexibility.

The design and construction of experimental prototypes with creativity and originality, involving a problem-solving process to develop skills in the use of structural, mechanical, and spatial geometric patterns (Diago, Arnau and González-Calero, 2018; González-Calero, Cózar, Merino and Villena, 2018; Martínez, Escamilla and Campos, 2019; Niño and Fernández, 2019; Restrepo y col., 2022).

Metodology

Project management involves the application of knowledge, skill, tools and techniques and It is constituted by the following stages:

– Project Planning

Considering the technical specifications of selected anthropomorphic arm-type industrial robot as a starting point, the necessary parameters for the production of the parts were identified, as well as the standards and measurements for the material available in Mexico.

– Project Management

The mechanical drawings from the robot manufacturer were interpreted, applying knowledge, skills, technical tools, and software (Jiménez Castro and Cerdas González, 2014).

The file type was selected according to the creation needs (element; sheet, solid part, assembly, drawing or animation), following the applicable standards and measurement systems.

– Manufacturing and Assembly Testing

To orient the part, the drawing is selected for the generation of the 2D drawing, followed by the identification of the geometric figure.

In the next step, to represent the shape, the drawn figure is defined, dimensioned, and/or constrained to give volumen and covert it into a 3D figure, using extrusion or swirling.

The process described above for making the parts needed to build an assembly is multiplied, inserting each part according to a defined plan, observing restrictions to define the position, orientation, and movement of the parts, until the process is complete and the file is saved.

Once the assembly is complete, check for interferences between parts (over-positioning of one or norte parts), and review measurements according to the planned design.

Next, generate the animation file, explode the assembly using the animation file, moving one part o a group of parts to positions where the animation will be located.

It is time to create a list of components needed to manufacture the system or the designed parts, documenting at a minimum: component name, part number, number of parts, and a brief description. Each part and/or component varies in function depending on the assigned configuration. Thus they must fit perfectly according to the intended mechanical design, in order to achieve a consistent and robust model (see Figure 1).

Box 1

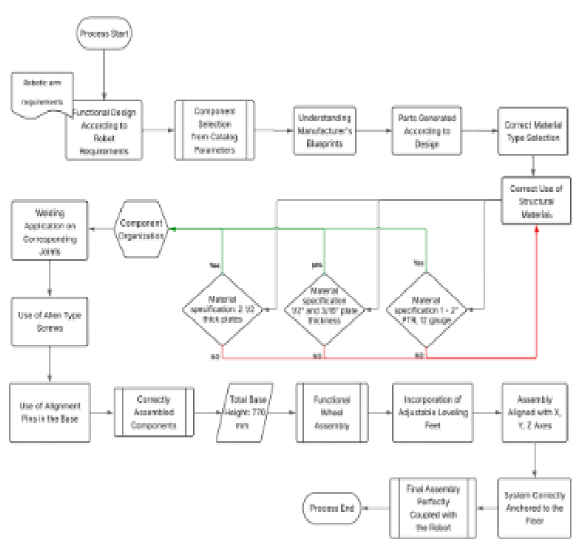

Figure 1
Flowchart for the CAD design of a mechanical base for an anthropomorphic industrial robot.

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– Evaluation

Using a checklist (see Table 1) with indicators that allow assessing aspect such as form representation and dimensional an functional compliance.

Box 2

Table 1
List of variables or factors

	Variables o Factors
1	Parts generated according to the design
2	Understanding of manufacturer's drawings
3	Proper assembly of parts
4	Functional wheel assembly
5	Organization of parts
6	Use of parts selected based on catalog parameters
7	Functional design according to robot requirements
8	Total base height: 770 mm
9	Correct use of 2" gauge 12 PTR
10	Use of 1/2" thick plates
11	Use of 2"x2" angle, 5/16" thickness
12	Use of 3/16" thick plate
13	Correct material type selection for each part
14	Final assembly perfectly coupled with the robot
15	Use of Allen-type bolts in connections
16	Welding applied in corresponding joints
17	Use of alignment pins on the base
18	System properly anchored to the floor
19	Incorporation of adjustable leveling feet
20	Assembly aligned with the X, Y, Z plans

It proposed an exploratory studies (Sampieri y col., 2014), it was decided to use a factorial design, as it allows the study of the effect of multiple independent variables (factors) on a dependent variable, followed by a principal components analysis with standardized data to help reduce the dimensionality of the data, identifying the relationships between variables and extracting principal components that explain most of the variance (Martens y col., 2012).

Results

– Project Management

The list of components and requirements necessary for the development of the mechanical base of an antrhropomorphic arm-type industrial robot is shown (see Table 2).

Box 2

Table 2
List of components

ITEM	QUANTITY	PART NUMBER / DESCRIPTION
1	4	PTR 2in - 117mm
2	4	Plate 14in - 85mm
3	4	HT515FRHTGA1 Wheel 2in - 67mm
4	1	Post 6in
5	4	PTR 2in - 1000mm
6	1	Plate 12in - 190mm
7	1	KR3 R540
8	16	JIS B 1174 - M5 x 12
9	4	ISO 7089 - 8
10	4	NF E 25-515 - W8
11	4	AS 1420 - 1973 - M8 x 40

Note: The use of a hybrid system of units (in and mm) is required, given the conditions of raw material supply in Mexico.

– Manufacturing and Assembly Testing

Project structure, mechanical modeling and incorporation of part and/or components, taking into account their specific appropriate characteristics and meeting the proposed structural plans.

Below are different angles of the mechanical base of an antrhropomorphic arm-type industrial robot (see Figure 2, 3, and 4)

Box 3

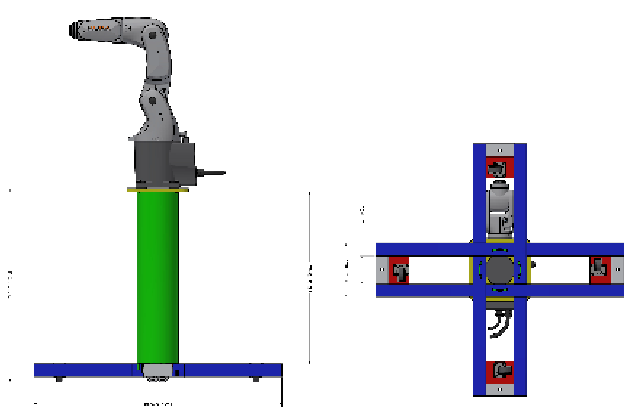

Figure 2
Overview of the robot base

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Box 4

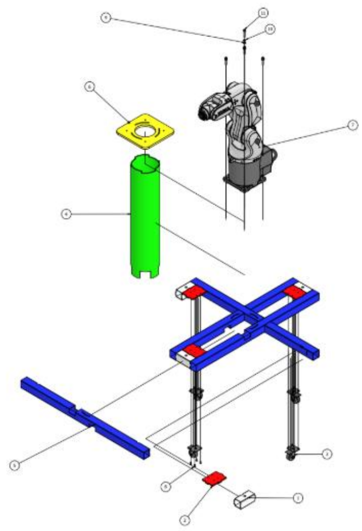

Figure 3
Dismantled or exploited

The exploded view is a type of technical drawing, useful in the assembly of materials and is created by combining assembly files.

Box 5

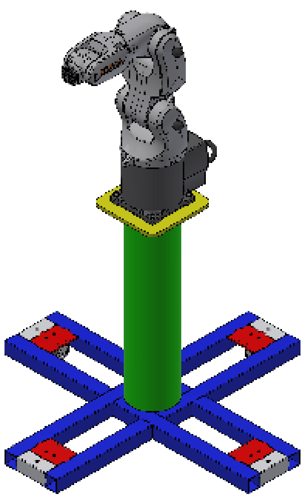

Figure 4
Isometric

Tree-dimensional simulation o visual representation of an object to facilitate understanding of its shape and dimensions. Due to the group conditions, the simple size used was 22 participants. A 95% confidence level was established, and statistical analysis was performed using Minitab 20 software. Although the simple size may seem insufficient to detect small differences, it is considered adequate to explore the relationship between the main variables. The analysis began with Pearson pairwise correlation test, and the most strongly correlated criteria were identified (see Table 3).

Box 6

Pearson Pairwise Correlations

Sample 1	Sample 2	N	Correlation	95% CI for Correlation	p-value
Manufacturer's drawing comprehension	Parts generated according to the	22	0.964	(0.914, 0.985)	0.000
Correct part assembly	Parts generated according to the	22	0.567	(0.190, 0.798)	0.006
Functional wheel assembly	Parts generated according to the	22	0.567	(0.190, 0.798)	0.006
Part organization	Parts generated according to the	22	1.000	(*,*)	*
Use of parts taken from inventory	Parts generated according to the	22	0.869	(0.707, 0.945)	0.000
Functional design per requirements	Parts generated according to the	22	0.690	(0.379, 0.861)	0.000
Total base height: 770 mm	Parts generated according to the	22	0.567	(0.190, 0.798)	0.006
Proper use of 2" PTR calibration	Parts generated according to the	22	0.869	(0.707, 0.945)	0.000
Use of parts with 1" thickness	Parts generated according to the	22	1.000	(*,*)	*
Use of 2"x1" angle with 5" thickness	Parts generated according to the	22	0.516	(0.121, 0.770)	0.014
Use of parts with 3/16" thickness	Parts generated according to the	22	1.000	(*,*)	*

Table 3
Fraction of Pearson pairwise correlations

As an example, stongly correlated criteria include: Final Assembly Perfectly Coupled with the Robot and Functional Design According to Robot Requirements. Other important relationships include assembly aligned with the XY, XZ, and YZ planes, and correct assembly of parts.

Box 7

Strongly Correlated

Correctly anchored system	Correctly assembled parts	22	0.726	(0.438, 0.879)	0.000
Incorporation of leveling feet	Correctly assembled parts	22	0.528	(0.137, 0.777)	0.011
Assembly aligned with the plans	Correctly assembled parts	22	0.736	(0.456, 0.883)	0.000

Table 4
Correlations

After confirming importan correlations, a standardization was applied in order to test a Factor Analysis followed by the Principal Components Test, it was tested with 5 strongly related factors, obtaining that the parts generated according to the robot design explain 98.7% of the variability, fulfilling the purpose of defining the structure of interrelations (see Table 5).

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Box 8

Table 5

Tested with five strongly related factors

Unrotated Factor Loadings and Communalities

Variable	Factor1	Factor2	Factor3	Factor4	Factor5	Communality
Parts generated according to spec_1	0.957	-0.238	0.063	0.067	0.083	0.987
Fabrication timeline compressor_1	0.92	-0.306	0.119	0.093	0.052	0.965
Corrective part assemblies_1	0.768	0.374	-0.087	-0.201	-0.016	0.916
Mid-functional assembly_1	0.572	-0.104	0.441	-0.552	-0.099	0.847
Part organization_1	0.957	-0.238	0.063	0.067	0.083	0.987
Use of parts sourced from inventory_1	0.886	-0.182	-0.366	-0.102	-0.03	0.981
Functional design per requirements_1	0.82	0.475	0.175	0.178	-0.041	0.961
Total base height_1	0.74	0.481	-0.188	0.142	-0.297	0.922
Proper use of PTR_7 calibration_1	0.811	-0.299	0.038	0.118	0.213	0.808
Use of plates with specified material_1	0.957	-0.238	0.063	0.067	0.083	0.987
Use of 2'x2' angle with correct thickness_1	0.492	-0.338	0.298	0.222	-0.671	0.945
Use of 3'x6' plates with specified material	0.957	-0.238	0.063	0.067	0.083	0.987
Correct fastener type selection_1	0.896	-0.185	-0.366	-0.102	-0.03	0.981
Perfectly coupled final assembly_1	0.835	0.299	0.08	0.295	0.219	0.928
Use of type Al fasteners_1	0.7	0.146	-0.488	0.134	0.038	0.769
Proper welding application_1	0.694	0.49	0.174	0.293	-0.05	0.84
Use of aligned handles_1	0.703	0.487	0.194	-0.023	0.186	0.804
Correctly anchored system_1	0.654	-0.304	-0.061	-0.575	0.01	0.844
Incorporation of leveling feet_1	0.754	-0.28	0.273	0.155	0.144	0.767
Assembly aligned with reference axes_1	0.866	0.026	-0.242	-0.205	-0.291	0.936
Metric						
Explained Variance	13.045	2.092	1.107	1.098	0.821	18.163
% of Total Variance	0.652	0.105	0.055	0.052	0.041	0.908

Subsequently, factors were eliminated, to use only the three main stongly related factors and the explanation of 97.5 % of the relationships was obtained (see Table 6).

Box 9

Table 6

Tested with three strongly related factors

Unrotated Factor Loadings and Communalities

Variable (English Translation)	Factor1	Factor2	Factor3	Communality
Parts generated according to spec_1	0.957	-0.238	0.063	0.975
Drawing compensation in fab_1	0.92	-0.306	0.119	0.954
Correct part assembly_1	0.768	0.525	-0.087	0.873
Functional wheel assembly_1	0.572	-0.104	0.441	0.533
Part organization_1	0.957	-0.238	0.063	0.975
Use of parts taken from inventory_1	0.896	-0.182	-0.366	0.97
Functional design per requirements_1	0.82	0.475	0.175	0.928
Total base height: 770_1	0.74	0.481	-0.188	0.814
Correct use of 2" PTR calibration_1	0.811	-0.299	0.038	0.749
Use of plate with thickness_1	0.957	-0.238	0.063	0.975
Use of 2"x2" angle with thickness_1	0.492	-0.338	0.298	0.445
Use of 3/16" thick plate_1	0.957	-0.238	0.063	0.975
Correct fastener type selection_1	0.896	-0.182	-0.366	0.97
Perfectly coupled final assembly_1	0.835	0.299	0.08	0.792
Use of type Al fasteners_1	0.7	-0.146	-0.488	0.75
Welding application_1	0.694	0.49	0.174	0.752
Use of alignment pins_1	0.703	0.487	0.194	0.769
Correctly anchored system_1	0.645	0.304	-0.061	0.513
Incorporation of leveling feet_1	0.754	-0.28	0.273	0.722
Assembly aligned with reference axes_1	0.866	0.026	-0.242	0.809
Metric				
Explained Variance	13.045	2.092	1.107	16.244
% of Total Variance	65.20%	10.50%	5.50%	81.20%

The graph shows three strongly related factors (see Figure 5).

Box 10

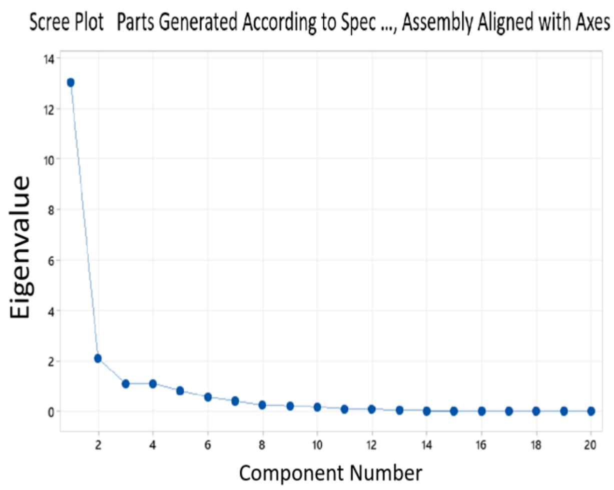

Figure 5

Scree chart showing three main factors

Finally, the matrix of components that can be integrated for further analysis is presented:

Generated Parts, Understanding of Manufacturer drawings and Correct Assembly of Parts.

Conclusions

Data analysis began with the confirmation of significant correlations. Standardization was applied to test a Factor Analysis followed by the Principal Components test. The matrix of components that can be integrated for subsequent analysis was obtained: Generated Parts, Understanding of Manufacturer's Drawings, and Part Assembly Correctly, as they explain 97.5% of variability.

Any branch of industry, science or technology can benefit from computer-aided design, analysis, and manufacturing, increasing the quality, precisión, and productivity of almost any ítem or activity, thereby improving the quality of life for humans.

As future lines of research, we propose evaluating various ways of working that involve the convergence of digital technologies and hardware to improve processes, simulate multidimensional physical models, and reduce costs (Pérez, Niño y Fernández, 2020). It should be noted that this study is not without limitations derived from the selection of analyses; therefore, it should be treated with caution.

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Availability of data and materials

The authors may make unshared data used to generate the results reported in the article available to interested parties upon request.

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