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Article

Graphical Interface in MATLAB for design and analysis of reflectors for lighting systems or solar collectors on parabolic surfaces

Interfaz gráfica en MATLAB para el diseño y análisis de reflectores para los sistemas de iluminación o colectores solares en superficies parabólicas

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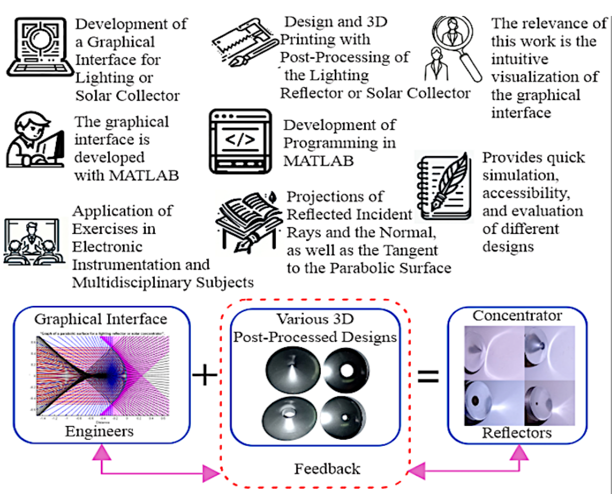
Abstract

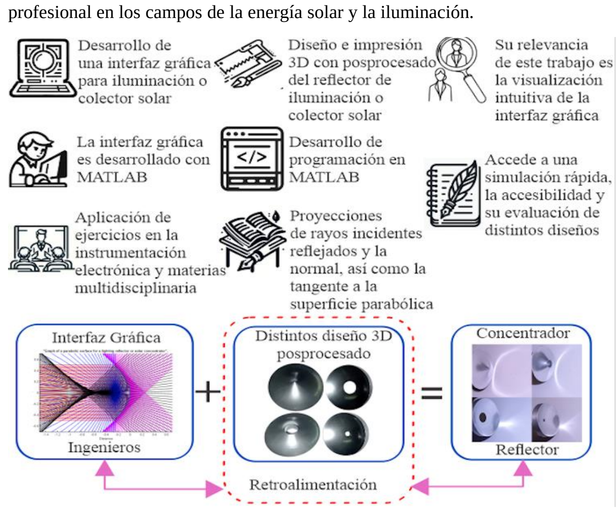
This project introduces the successful development of a MATLAB graphical interface for the design and analysis of reflectors and solar concentrators on parabolic surfaces. The integration of spline techniques for precise modeling of these surfaces has been implemented, along with the capability to generate STL files for 3D printing. The interface not only enables detailed and adaptable design of reflectors but also includes an advanced simulator for projecting incident rays and analyzing their reflection on the parabolic surface, focusing specifically on the focal point location. This has led to a significant increase in the efficiency of solar concentrators and lighting systems by enabling the precise placement of absorbers to maximize energy transfer. The obtained results confirm the initial hypothesis, demonstrating that the interface enhances the precision and efficiency in the design of these systems, thereby offering a valuable tool in both educational and professional realms in the fields of solar energy and lighting



Interface, Graphical, Concentrator

Resumen

Este proyecto presenta el desarrollo exitoso de una interfaz gráfica en MATLAB para el diseño y análisis de reflectores y concentradores solares en superficies parabólicas. Se ha integrado el uso de técnicas de spline para el modelado preciso de estas superficies, así como la capacidad de generar archivos STL para su impresión en 3D. La interfaz no solo permite un diseño detallado y adaptable de reflectores, sino que también incluye un simulador avanzado para proyectar rayos incidentes y analizar su reflexión en la superficie parabólica, enfocándose específicamente en la localización del punto focal. Esto ha permitido un incremento significativo en la eficiencia de los concentradores solares y sistemas de iluminación al posibilitar la colocación precisa de absorbedores para maximizar la transferencia de energía. Los resultados obtenidos confirman la hipótesis inicial, demostrando que la interfaz mejora la precisión y eficiencia en el diseño de estos sistemas, ofreciendo así una herramienta valiosa tanto en el ámbito educativo como profesional en los campos de la energía solar y la iluminación.



Interfaz, Gráfica, Concentrador

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Introduction

The transition to renewable energy sources is a crucial step in the fight against climate change and environmental pollution. In this context, solar reflectors and collectors emerge as key components, allowing an optimised capture of solar energy, which is essential to reduce our dependence on fossil fuels and reduce greenhouse gas emissions (Valdés, 2020). These advances not only aim to combat global warming, but also promote sustainability and innovation in the field of energy technologies. Solar resource assessment is the first critical step for the effective utilisation of this natural energy, which implies a detailed study of the temporal and spatial distribution of solar radiation. For Mexico, which is among the five countries with the highest solar energy generation potential, this assessment is even more relevant. With an average of 5 kilowatt hours per square metre per day, Mexico has a gross solar energy potential that is 50 times greater than the energy currently generated in the country, a figure that highlights the paradox of its current dependence on fossil fuels for electricity generation. Aware of this reality and the fact that fossil fuel power generation will not be economically sustainable or environmentally friendly in the long term, Mexico has focused on the development of renewable technologies. Photovoltaic panels, for example, are presented as a promising solution thanks to their durability, low maintenance and an initial investment that becomes more competitive every year, facilitating their adoption (Velázquez et al, 2020). Research on solar energy use in Mexico stands out for its focus on sustainable and efficient solutions, such as bioclimatic architecture, water heating and photovoltaic systems. Flores et al. (2020) highlight the importance of Mexico's geographical location for solar irradiation, emphasising advanced technologies such as parabolic dish systems. These systems, optimised through ray-tracing software, allow for higher solar absorption and reduced losses by adjusting key parameters such as geometry and optical properties. In parallel, Mexico's role on the global stage in the fight against climate change is reinforced by its participation in international agreements such as the Montreal and Kyoto Protocols. Juárez (2008) analyses how these commitments underline the need for global policies and joint actions to mitigate the effects of climate change and move towards sustainable development. Mexico's ratification of these treaties demonstrates its commitment to protecting the atmosphere and the ozone layer.

However, Escalona (2020) warns of the challenges facing global warming mitigation due to neoliberal policies that favour transnational corporations. The influence of these entities on global policy decisions has exacerbated environmental problems by prioritising corporate profits over sustainability. This analysis suggests the need to reform public policies to incorporate environmental solutions not only in rural but also in urban areas by promoting technologies such as solar concentrators and floodlighting. The implementation of these systems in urban areas can significantly contribute to raising awareness of carbon emissions reduction and the use of renewable energy sources, as has been observed with the increasing adoption of solar heaters. This sequence of ideas illustrates the complexity of the energy and environmental landscape in Mexico, highlighting the interplay between technological innovation, international commitments and public policies. The transition to a more sustainable and efficient energy model is imperative to address climate change, and will require a combination of technological advances, international cooperation and policy reforms aimed at sustainability and environmental protection. Solar thermal energy represents an innovative and sustainable solution to meet heat needs in various sectors by efficiently harnessing solar radiation. This technology, which transforms the sun's energy into heat, is emerging as an economically viable alternative to fossil fuels, contributing significantly to reducing pollutant emissions and combating climate change. Osornio et al. (2022) highlight the versatility of solar thermal devices, which adapt to different temperature ranges according to specific heat demands, from residential to industrial applications. The positive impact of solar thermal on quality of life is remarkable, especially in urban centres where its use can decrease the prevalence of respiratory diseases linked to air pollution. Although the deployment of this technology in the industrial sector is still limited compared to the residential sector, the trend shows an accelerated growth in the implementation of new solar thermal plants globally. These systems are classified into non-concentrating, such as flat-plate collectors, and concentrating, which include technologies such as the compound parabolic concentrator and the central tower receiver, and are differentiated by the temperatures they can reach. Solar concentrators, in particular, have gained ground in the harnessing of solar energy for electricity and heat generation.

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As a renewable and non-conventional source, solar energy opens up a range of possibilities for immediate application in conventional uses, including food cooking, highlighting its potential to generate income and offer sustainable alternatives in different fields (Linares et al., 2020). This scenario reflects the growing relevance of solar thermal energy and solar concentrators in the global energy matrix, underlining the importance of moving towards clean energy sources that favour sustainability and competitiveness in various sectors. Solar energy is positioning itself as a viable and sustainable alternative to non-renewable energy sources such as fossil fuels. The International Renewable Energy Agency IEA, 2020[a], highlights that investment in solar photovoltaic energy has experienced significant growth, with 2018 being the year with the highest implementation of projects. Despite a slight decline in subsequent years, solar energy is projected to continue its expansion in the near future. This growth is driven by a reduction of up to 82% in the cost of solar system components, such as photovoltaic cells, and a decline in the price of solar power to $0.063 cents per kWh. These trends have motivated numerous companies to switch from fuels such as coal to solar power, achieving significant savings in CO2 emissions and considerable economic benefits in 2019 IEA, 2020b. In addition to electricity generation, solar energy is also harnessed for heat production through heat exchanger systems that use plates or tubes through which a fluid circulates. This thermal approach, which can reach temperatures above 150°C, has the potential to be used in turbines to generate electricity, although its most frequent use is domestic and industrial. In 2019, the global installed capacity of these systems reached 6,289 GW, demonstrating the broad spectrum of solar energy applications, from photovoltaic and thermoelectric generation to water heating and food cooking (Acosta et al., 2023). Solar thermal energy, captured through various technologies, has the potential to meet a wide range of residential and industrial needs. This technology converts sunlight into heat, a process known as solar heating, and transfers this heat to a working fluid for use in a variety of applications. Common applications include domestic hot water supply, space heating, product drying, and steam generation for industrial processes. Continued research and innovation promise to further reduce the production and sales costs of these technologies, encouraging their adoption through policy incentives.

Finally, solar thermal energy used in the industrial sector has advanced significantly, making it possible to reach temperatures suitable for specific industrial processes, ranging from 60°C to 400°C. This range of temperatures opens the door to the adoption of solar thermal technologies. This temperature range opens the door to complex applications, including electricity generation, demonstrating the versatile potential of solar thermal to contribute to a cleaner and more sustainable energy future (González et al., 2020). Solar energy emerges as a promising solution to the global energy crisis and climate change, standing out for its ability to generate energy efficiently and sustainably. Clemente y Espinoza **(**2021**)** highlight the importance of concentrated solar power technologies, such as parabolic and central tower concentrators, for their efficiency in producing heat at high temperature, which optimises solar absorption and minimises heat losses. In the research field, Panaroni et al. (2021) explore the optical efficiency of a prototype parabolic solar concentrator, employing methodologies such as the constant mass calorimeter and the modified Hartmann optical scanning test. Validation of these methods reveals comparable optical efficiencies, highlighting their practical and economic value for the design and evaluation of solar technologies in renewable applications. Given the complexity and high cost associated with solar concentrator fabrication, optical simulations represent an invaluable tool. Narvaez (2021) discusses how these simulations facilitate the precise definition of critical characteristics, such as focus and heat flux distribution, thus enabling efficient optimisation that can avoid costly remanufacturing. Simulation software such as Solar Trace and Tonatiuh offer advanced optical modelling capabilities for applications in concentrated solar power systems.

On the other hand, research on solar cookers by Echazú et al. (2000) analyses the spectral reflectance of different materials, including aluminium and stainless steel. This study provides important insights into heat balance and economic feasibility, offering guidelines for the design of more efficient solar cookers. These advances and studies demonstrate the continued commitment to the improvement and application of solar energy, from high-tech solar concentrators to practical applications such as solar cookers, highlighting solar energy as a fundamental building block for a sustainable and efficient energy future.

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While it is true that methods other than post-processing can be used, according to Lanfranchi, and Comoretto (2024) conducted a groundbreaking study, published in Chemical Engineering Science, they have designed and fabricated dielectric mirrors, called aegides, capable of reflecting near-infrared radiation using various polymer pairs, from common to specialised polymers. Using a quantitative approach, they predicted the heat-reducing efficiency of these aegides, allowing the design of optimised reflectors for various practical applications. They used spin-coating techniques to create the aegides, alternating layers of polymers with different refractive indices on glass substrates.

The programming of graphical interfaces in environments such as MATLAB has undergone a significant evolution, offering tools such as GUIDE and App Designer that facilitate the creation of user interfaces using drag-and-drop techniques. These tools not only allow seamless integration of graphical components such as buttons and text fields, but also enable the incorporation of complex programming logic, optimising user interaction with the application. This approach greatly improves accessibility and efficiency in the development of advanced graphical applications. In the academic and professional environment, several works have been developed using computer-aided tools for the programming of graphical interfaces. Espinoza et al. (2023) illustrate this trend by developing a graphical user interface (GUI) in Python for a thermohaline convection simulator, demonstrating the importance of efficient pre- and post-processing tools in numerical analysis. Such developments emphasise the relevance of GUIs in visualising results and setting simulation parameters, highlighting their value as educational resources in fields such as computational science. Digital graphical interfaces have also found innovative applications outside the traditional domain, such as in cinema, where they facilitate a more dynamic and enriching interaction of the viewer with the film content. Villegas (2023) explores how these technologies contribute to the construction of interactive narratives, marking a move towards formats that integrate digital technology to create immersive viewing experiences. In the construction sector, solar energy is emerging as a sustainable alternative, thanks to technological advances in active and passive systems and cost reductions.

This transition is supported by computational tools that make it possible to assess the feasibility of implementing solar systems, optimising comfort and energy efficiency in buildings. Fondoso et al. **(**2021**)** highlight the use of CAD programs and software such as DesignBuilder to calculate solar radiation on different urban geometries, while noting challenges in compatibility between different programs. This overview reflects how the intersection of GUI programming, simulation and numerical analysis, and practical applications in sectors such as film and construction are driving significant innovations. The integration of these technologies not only facilitates the development of advanced solutions, but also promotes deeper understanding and broader applications in solar energy and other areas of interest. The integration of the graphical interface in the analysis and simulation of complex phenomena, such as quantum states of light, represents a significant advance in scientific research. Fernandez (2022) highlights the implementation of an accessible graphical interface to facilitate quantum tomography, which underlines the relevance of intuitive interfaces in the handling of experimental and simulated data.

This practical and theoretical approach not only improves the understanding of optics and quantum information, but also demonstrates how programming tools can be crucial in the advancement of science. In education, Kariadinata et al. (2023) developed a graphical user interface (GUI) in MATLAB focused on teaching statistics. Using the 4D research and development methodology, this study facilitates the learning of statistical concepts through a user-friendly GUI, demonstrating the effectiveness of graphical interfaces in mathematics education. MATLAB programming has also been applied in the evaluation of parabolic surfaces, as illustrated by the work of Santamaria (2019).

This study presents the use of the Razor's Edge Interferometer in the 2f array to evaluate the optical quality of lenses and reflecting surfaces, offering a cost-effective and versatile alternative to traditional methods.

The ability to generate and analyse interferograms using commercial software emphasises the importance of programming graphical interfaces in optimising experimental results.

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In several works where concentrators implement ray traces in order to analyse radiation behaviour such as Chen and Khosa (2024) both carried out a comprehensive analysis on a photovoltaic/thermal (PV/T) concentrator system employing nanofluid spectral splitting with a triangular receiver, as detailed in their publication in Applied Thermal Engineering. This study proposes a linear Fresnel CPV/T system combined with a triangular cooling duct and an Ag@SiO2/ethylene glycol (EG) nanofluid filter with the aim of boosting the overall system performance. Using an integrated approach combining the Monte Carlo ray tracing method (MCRT) with the Finite Volume Method (FVM), they modelled and evaluated the thermal, electrical and overall efficiency of the system under various operating conditions.

Knowledge of conic curves, from their historical applications in optics to their relevance in modern lighting engineering and design, has been fundamental to technological development. The history of conic curves, as described in Britannica (2023), and their application in Kepler's law of planetary motion, Galileo's projectile trajectory, and architectural and technological innovations, demonstrates their lasting impact on multiple disciplines.

Recently, Kishine and Maeda (2023) explored how the visual perception of parabolas varies with viewpoint, a study relevant to the design of reflectors and solar collectors. This analysis provides a mathematical basis for understanding how geometry affects the distribution and perception of light, optimising the efficiency of these practical applications. These papers illustrate the interconnection between graphical interface programming, quantum theory, educational statistics, experimental optics and geometry, highlighting the essential role of the graphical interface in simplifying and advancing complex research and applications. The paper examines John Wallis' contributions to the rectification of the parabola through the use of numerical series, illustrating a landmark mathematical approach to tackling complex geometric problems. Wallis applied innovative techniques for his time, highlighting the relevance of rectifying curves and generating solids of revolution from curves, which is fundamental to various scientific applications such as ballistics, optics and astronomy (Florio,2022).

Objective

To develop a graphical interface in MATLAB, specialised in the design, analysis and simulation of reflectors and solar collectors with parabolic surfaces. This advanced tool will allow the generation of graphs and coordinate points for use in advanced surface modelling programs, such as the spline method. In addition, it will facilitate the creation of 3D files of revolution, to generate files in formats such as *.stl or *.gcode. The graphical interface will provide the solution to store graphs and coordinate points of surfaces, making it ideal for application in educational and professional contexts. This will provide an essential tool for teaching and realisation of projects in the field of solar energy and lighting. Additionally, a validation process will be carried out to ensure the physical feasibility and constructive efficiency of the generated 3D models.

Hypothesis

If a graphical interface is implemented in MATLAB for the design and analysis of parabolic surfaces, together with the generation of STL files for 3D printing, then the accuracy and efficiency in the design and development of reflectors and/or solar concentrators will be significantly improved. This tool will make it easier for the user to visualise and simulate incident and reflected rays, optimising the location of the effective focal length and thus improving energy harvesting in practical applications. In addition, the ability to define specific upper and lower limits on the designer's surface of these systems will offer greater flexibility and adaptability, making it ideal for application in educational contexts of teaching-learning and will result in a significant improvement of the performance of solar concentrators and/or reflectors under various environmental and design conditions with post-processing.

Methodology and development

The graphical interface was developed in the Measurement and Instrumentation Laboratory of the Centro Tecnológico de la Facultad de Estudios Superiores Aragón, with the objective of designing solar concentrators or lighting reflectors. The design process was started using the parabolic equation, then a 90-degree clockwise rotation around the origin was performed.

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This rotation modifies the x and y coordinates, interchanging them and inverting the sign of one of them. The rotation of a point (x, y) around the origin at an angle θ clockwise is executed using Equations 1 and Equation 2, as described in the following formulae:

$$x' = x\cos(\theta) + y\sin(\theta) \quad [1]$$

$$y' = -x\sin(\theta) + y\cos(\theta) \quad [2]$$

For a rotation of 90 degrees (θ=90^°), both Equations 3 and 4 simplify to:

$$x'=y \quad [3]$$

$$y'=-x \quad [4]$$

Applying these transformations to the equation $y=^{ax2}$, we exchange x for y and y for -x. This gives us the following Equation 5 and Equation 6:

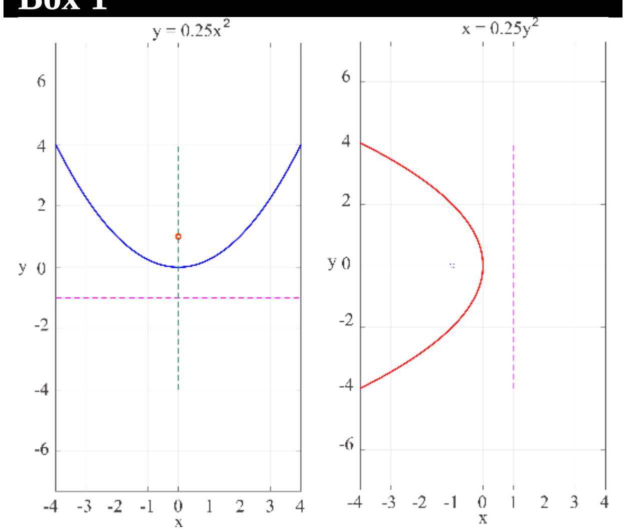
$$-x = ay^2 \quad [5]$$

Reordering:

$$x = -ay^2 \quad [6]$$

Now, Figure 1 shows both parabolic functions $y = -ayx^2$ y $x = -ay^2$ for a specific value of a, e.g., $a = 0.25$.

Box 1



(a) (b)

Figure 1

a) Graph of the parabola. b) Rotation of the parabola

Now, both parabolic functions will be plotted. $y = ax^2$ y $x = -ay^2$ par at a specific value of a, with intervals from 0.2 to 1 as shown in Figure 2, opens up as the value a=1

Box 2

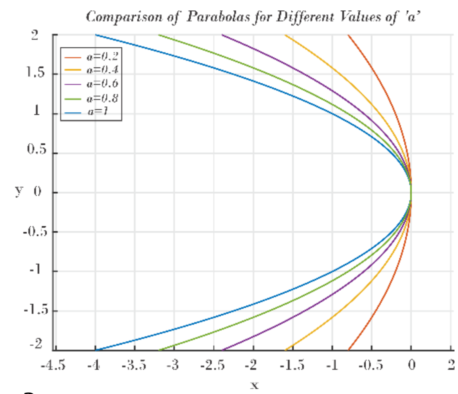


Figure 2

It can be seen that the value does vary or the parabola opens up or becomes narrower when it has the value a=1

The parabola is defined as the set of all points that are at the same distance from a fixed point, called the focus, and a fixed line, called the directrix. For simplicity, let us assume that the focus is at the point F (0, p) and the directrix is the horizontal line y=-p, where p is a positive distance. The vertex of the parabola is at the origin V (0,0) and is the midpoint between the focus and the directrix. We take a generic point P(x,y) on the parabola and by definition, the distance from P to the focus F is equal to the distance from P to the directrix. The distance is described in Equation 7, which is the same equation used in the formula for the distance of P of F:

$$PF = \sqrt{(x-0)^2 + (y-p)^2} = \sqrt{x^2 + (y-p)^2} \quad [7]$$

The distance from P to the directrix is given in Equation 8:

$$PD = | y - (-p) | = | y + p | \quad [8]$$

Equating the two distances in Equation 7 and Equation 8, since PF=PD, and eliminating the square root and the absolute value by squaring both sides of the equality gives Equation 9:

$$x^2 + (y-p)^2 = (y-p)^2 \quad [9]$$

We expand both equations on both sides and simplify and get Equation 10:

$$x^2 + y^2 - 2yp + p^2 = y^2 + 2yp + p^2 \quad [10]$$

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The terms are cancelled y^2 and p^2 on both sides and divide by 4p to keep it unchanged to obtain Equation 11.:

$$x^2 = 4py \quad [11]$$

Divide on both sides by 4p to isolate y, giving Equation 12:

$$y = \frac{1}{4p}x^2 \quad [12]$$

The deduction of the upward-opening parabola with the vertex at the origin was made earlier.. Where $a = \frac{1}{4p}$, For Equation $x = ay^2$, S Following a similar process, if the focus is at (p,0) and the directrix is the vertical line x=-p, it is shown in Equation 13:

$$x = \frac{1}{4p}y^2 \quad [13]$$

In this case, the parabola opens to the right. The constant a in the equation of the parabola $x = -ay^2$ afects the "width" or "aperture" of the parabola. To calculate the value of a, the information needed would be the distance from the vertex to the focus or a specific point through which the parabola passes. The focus of a parabola that opens horizontally is at a distance of $\frac{1}{4a}$ from the vertex, along the axis of symmetry of the parabola. Since the focus has been given at the position (-0.25,0), this means that $\frac{1}{4a}$ =0.25. Then, to find a, a is removed from Equation 14 and thus the value of a is calculated:

$$\frac{1}{4a} = 0.25 \quad [14]$$

To solve for the constant a we have its value of 0.25 as shown in Equation 15:

$$a = \frac{1}{4\times 0.25} \quad [15]$$
$$a = 1$$

This means that the value of a is 1 for the given parabola, which was already mentioned in the initial description. This confirms that the parabola is quite "narrow", since a value of a equal to 1 indicates that it opens at a faster rate than if a were less than 1. If a is based on the geometric definition of the parabola which is the set of all points that are equidistant from a fixed point called the "focus" and a fixed line called the "directrix". If we know the distance from the vertex to the focus (denoted as f), then $a = \frac{1}{4f}$.

The directrix is the same distance from the vertex, but in the opposite direction to the focus. If we have a specific point through which the parabola passes, say (x_0,y_0), we can substitute it into the equation $x=ay^2$ and solve for a: as shown in Equation 16:

$$a = \frac{x_0}{{y_0}^2} \quad [16]$$

The parameter a is called the "parabola parameter" and is directly related to the "focal length", which is the distance from the focus to the vertex of the parabola. The focal length f and the parameter a are related by the equation $f = \frac{1}{4a}$ pa a is a parabola whose vertex is at the origin and which is open along the x-axis. In short, a is an indicator of the curvature of the parabola: the larger the absolute value of a, the steeper the curvature, and the smaller it is, the flatter or more open the curve, the description of the graphical interface we worked with is shown in Figure 3.

Box 3

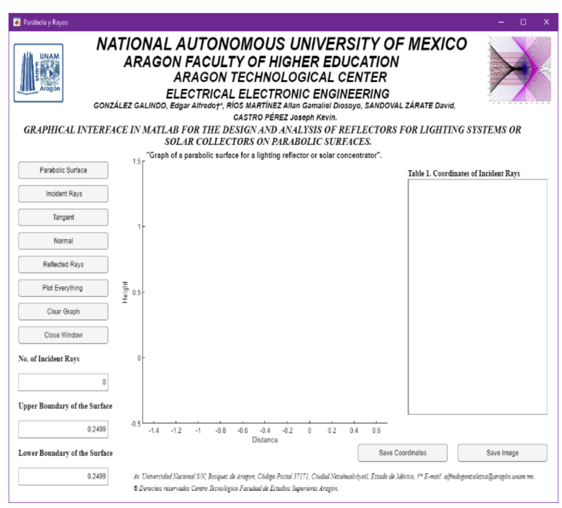

Figure 3
Graphical interface that simulates ray traces for a parabolic surface

The interface allows us to design parabolic surfaces, for this particular case the generated graph is shown, Figure 4a, the parabolic surface is generated where it will be the region of interest where the incident rays will be projected, as shown in Figure 4b.

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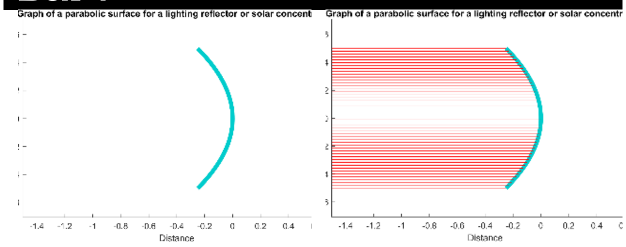
Box 4



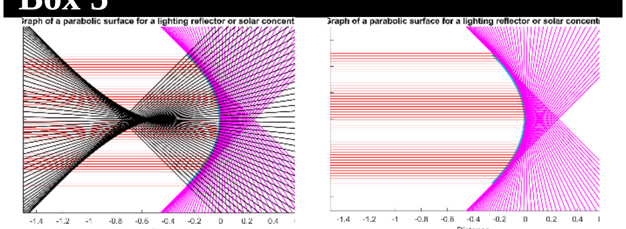
(a) (b)

Figure 4

a) Surface of interest. b) Surface ray tracing

In the same region, the interface allows the projection of lines tangent to the surface at each coordinate point where each incident ray touches the surface, as shown in Figure 5a. Knowing that the normal is perpendicular to each of the lines tangent to the surface, the interface also allows the projection of normal lines at each of the coordinates, as shown in Figure 5.

Box 5



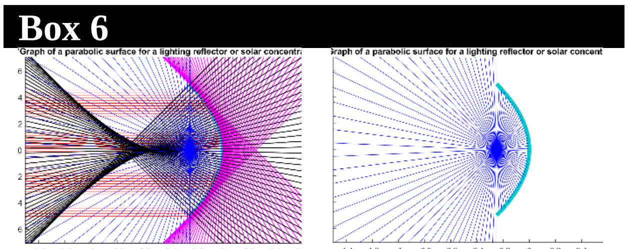
(a) (b)

Figure 5

a) Tangent at each coordinate point of the incident rays. b) Plot of the Normal which is perpendicular at each tangent point

In addition, the interface allows the projection of the reflected rays, shown in Figure 6a. If it is of interest to the user, the different types of rays to be observed in the simulation can be selected. Either incident rays, tangent rays, normal rays or reflected rays. The example in Figure 6b shows the projection of reflected rays without showing the projections of tangents and normals.

Box 6



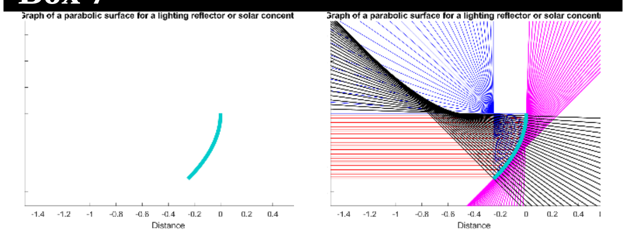
(a) (b)

Figure 6

a) Simulation of the rays, tangents, normals and reflected rays. b) Projection of the parabolic surface and the reflected rays

Another benefit of the graphical interface is that it allows selection of the region of interest on the parabolic surface. Boundaries can be set to delimit where the ray trace is to be projected as shown in Figure 7a. Similarly, the rays of interest that are required to be projected independently in the region of interest can be selected as shown in Figure 7b.

Box 7



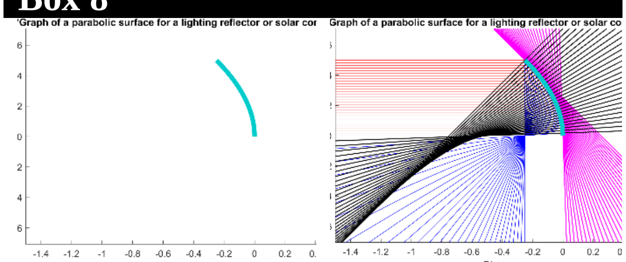
(a) (b)

Figure 7

a) Bounded surface in the negative region of y. b) Incident, tangent, normal and reflected rays from the bounded surface

This delimitation can also be performed on the positive side, as shown in Figure 8a. Applying also the required ray tracing on that delimited surface, showing the projection of all traces as shown in Figure 8b.

Box 8



(a) (b)

Figure 8

a) Bounded surface in the positive region of y. b) Incident, tangent, normal and reflected rays from the bounded surface.

The graphical interface can take the unconstrained values to generate surfaces in the regions of interest to the user, the region can be positive or negative or both regions.

As shown in Figure 9a, the surface is now fragmented into a central area bounded by its coordinates (-0.11, 0.3449) in the positive region of the y-axis and the coordinates (-0.11, -0.3449) of the negative region. The ray traces can be projected as required by the user, as shown in Figure 9b.

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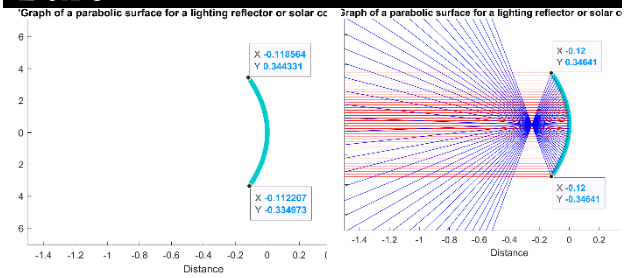
Box 9



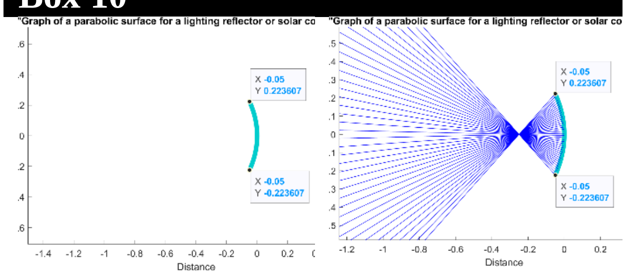
(a) (b)

Figure 9

a) Surface bounded at coordinates (-0.12, 0.3449) and (-0.12, -0.3449). b) Plotting of incident and reflected rays on this surface

The surface of interest, by extension, can be analysed in a smaller section by modifying the boundaries given by the coordinates shown in Figure 10.

Box 10



(a) (b)

Figure 10

a) Delimited minor surface of interest. b) Reflected beams on that surface

In its entirety, the graphical interface allows to delimit any section of the parabolic surface to be analysed.

Results

For the design of a parabolic surface in the graphical interface can facilitate a simulation of the behaviour of the ray traces and at the same time to be able to reconstruct from the graphical expressions the program allows us to store them, as well as the points of coordinates, with base to some techniques can be obtained the equation that satisfies to this surface in Figure 11 is appreciated that the graphical interface is very intuitive and easy to handle.

Box 11

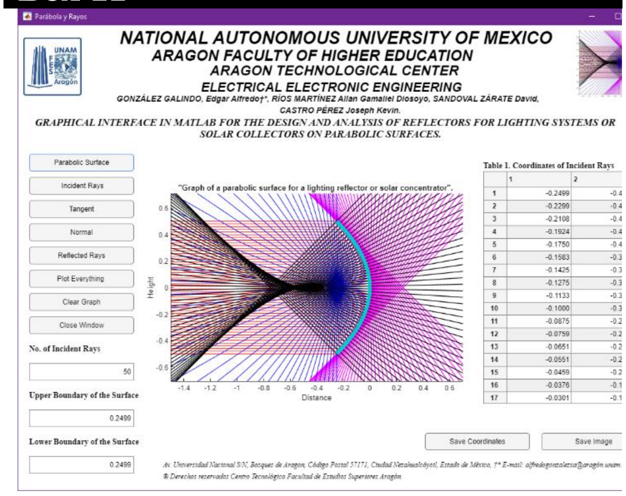


Figure 11

Simulation of a parabolic surface of interest with the projection of the incident, reflected, tangent and normal rays and the coordinate points where the incident rays intersect the surface

In Figure 12 we can see the folder where the generated files are stored, and inside are the coordinate points of the incident rays intersecting the parabolic surface for each design that was simulated, these coordinates can be used to reconstruct the surface.

Box 12

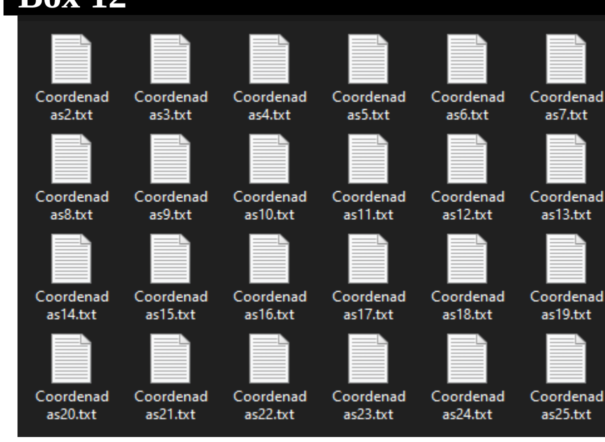


Figure 12

Files from incident lightning coordinates

There are techniques such as Lagrange, Polynomial Interpolation, Splines and B-Splines, Bezier Surfaces and NURBS (Non-Uniform Rational B-Splines) to use coordinate points to reconstruct surfaces, the graphical interface helps to generate the surface as shown in Figure 13 and at the same time generates the coordinate points, these could be used to apply any method mentioned above and obtain its equation that satisfies the surface to be analysed or reconstructed.

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Box 13

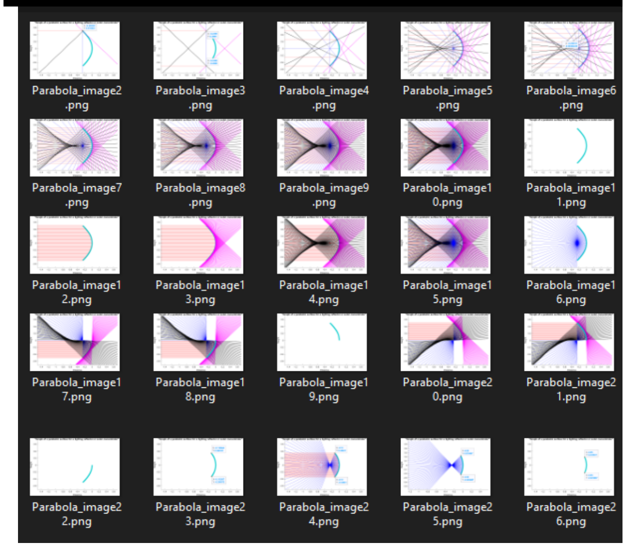
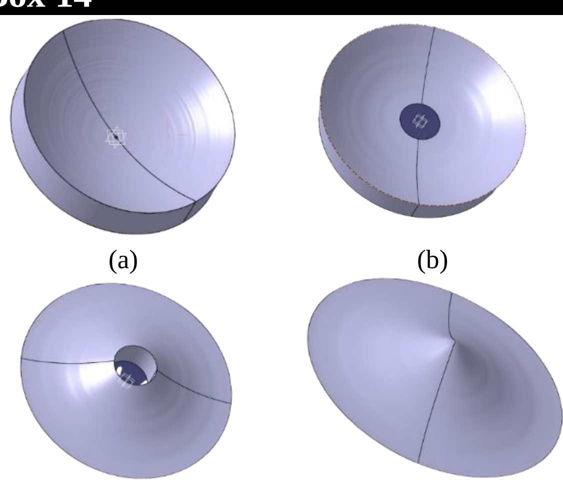


Figure 13
Simulation of a parabolic surface of interest with the projection of the incident and reflected rays, the tangent and normal and the coordinate points where the incident rays intersect the surface

In this particular case, the Splines technique was used to reconstruct the surface of the parabola and its region of interest and generate the *.stl file using a computer aided program (CAD), as shown in Figure 14.

Box 14

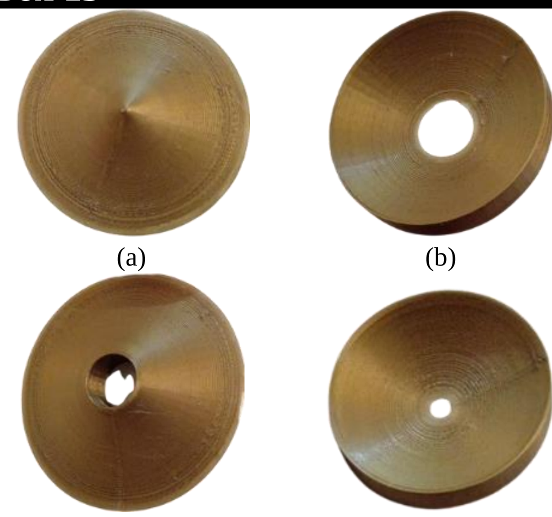


(a) (b) (c) (d)

Figure 14
a) 3D design of concave plane revolution, b) concave plane surface with central perforation c) sectioned surface obtaining its mirror at a distance to generate the revolution d) surface without central perforation space to generate a reflection either for lighting or solar collector its shape is toroidal

Figure 15 presents 3D prints using PLA filament. To carry out the chrome plating process for the surface is placed a paste to polish it using sandpaper of the following: 60, 180, 220, 540 and 1000, after sanding it with each calibre 2 layers of resonator is applied subsequently 2 layers of primer is placed, and then the chrome plating is applied to the 3D part.

Box 15



(a) (b) (c) (d)

Figure 15
Designing reflective surfaces in 3D printing using PLA filament

The post-process chrome plating stage refers to a technique and procedure applied after 3D printing that helps the surface to be plated with chrome. This process improves the surface properties of the part such as corrosion resistance, as well as durability and aesthetic appearance. The term "post-processing" indicates that chrome plating is performed after the part has been manufactured and after other surface treatments have been carried out. Post-processing includes several stages, such as surface preparation (cleaning, degreasing, and polishing), the chromium plating process itself, and post-chromium plating treatments such as polishing to improve the surface finish as shown in Figure 16.

Box 16

Figure 16
Images shown of the 3D parts with post-processing applied to improve surface reflection

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It is worth mentioning that post-process chromium plating offers several advantages, it also presents environmental and health challenges, particularly related to the handling and disposal of the chromium plating baths used in post-process chromium plating applications, in particular, in Figure 17 only four parts were chromed does not present a significant impact compared to the various industries that use this chromium plating technique (e.g. automotive, decoration and furniture, machinery, armament, aviation, bicycles, tools, etc.).

Box 17

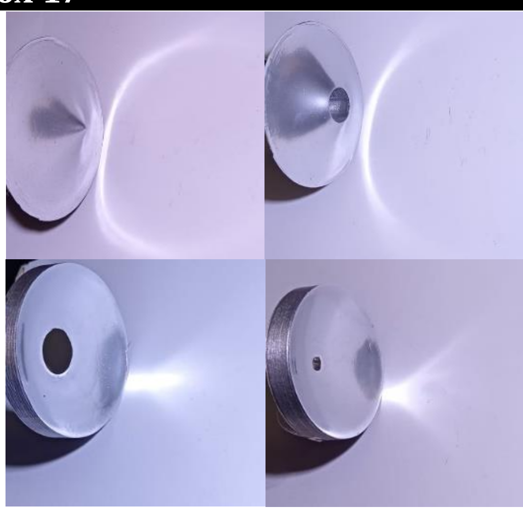

Figure 17
Reflective surfaces after post-processing, the reflection of incident rays to the parabolic surface is visualised

Figure 17 shows the result of the beam projection by visualising that the four chrome-plated parabolic surface shunts reflect and concentrate the light at the effective focal length, two of them generate a toroid and concentrate the illumination at a focal point.

Conclusions

The project has successfully achieved the design and development of parabolic surfaces developed using MATLAB making use of Spline techniques in Computer Aided Programs. The approaches allow accurate and adaptable modelling of these surfaces for specific applications in lighting and solar concentrators. The ability to generate STL files and take these designs to 3D printing has been a significant breakthrough. This not only demonstrated the feasibility of the theoretical designs, but also enabled the physical creation of models that could be used in practical applications and have the advantage of being scalable. A notable contribution has been the ability to modify and adapt parabolic surfaces beyond their traditional shapes.

This flexibility in design allows portions of the parabolic surface to be taken or the original design to be altered to meet specific needs, thus extending the scope for different applications. The results have confirmed that the designed surfaces are effective in concentrating light and illumination and the ray traces demonstrate that the concentration is carried at the effective focal length as shown in the interface graph and two of them concentrate the illumination in a toroidal shape. The project has also laid the foundation for future research and applications.

The developed interface can be a valuable tool for teaching-learning and research in the field of solar energy and lighting, providing an effective means to explore and develop new technologies in these fields.

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Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that might have appeared to influence the article reported in this paper.

Authors' contribution

Gonzalez-Galindo Edgar Alfredo: His contribution Graphical User Interface design: He was in charge of designing the graphical user interface (GUI) in MATLAB. This includes planning and creating the layout, buttons, sliders and input fields that will allow the user to interact with the application. This area required a meticulous approach to user experience to ensure that the tool is easy and accessible to manipulate.

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Diosoyo Ríos-Martínez Allan Gamaliel: His contribution to the development of the simulation and analysis logic: he was responsible for the development of algorithms that simulate the reflection of light on reflectors and the analysis of solar collectors or lighting systems. This required a solid understanding of the areas of physics and mathematics involving the parabolic surface and reflection as a light concentrator or solar concentrator to model them correctly in MATLAB.

Sandoval-Zarate David: His contribution was in Integration and Testing: In charge of integrating the different modules developed by the team, ensuring that the graphical interface works easily with the simulation and analysis algorithms. In addition, he is in charge of testing to identify and correct errors in post-processing.

It is essential for the GUI to be reliable and error-free prior to 3D printing.

*Castro-Perez Joseph Kevin:*His contribution was in documentation and physical testing: Responsible for documenting the development process of 3D printing using the spline technique, creating a user guide for the handling of the graphical interface. He will also develop use cases and laboratory practices to demonstrate the application of the tool in real engineering contexts where multidisciplinary subjects are taught. This will help to understand how to use the tool effectively.

Availability of data and materials

The data for this research is available according to the sources consulted.

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Abbreviations

GUI
MCRT
FVM
NURBS
STL

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