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Presentation of Content

In Volume number two as a first chapter we present, *Ultraviolet radiation quantification device for the prevention of Skin Cancer "Alert Skin"*, by VÁZQUEZ-CHACÓN, Verónica, CHÍO-AUSTRIA, Rosa María, AHUMADA-MEDINA, Albino and SÁNCHEZ-BARRERA, Erendira, with secondment in the Universidad Politécnica de Pachuca, as a second article we present, *Optomechanical design and implementation with 3D printing*, by GOMEZ-VIEYRA, Armando, VERGARA-VAZQUEZ, Karla Beatriz, FLORES-MONTOYA, David and MIRANDA-TELLO, José Raúl, with affiliation at the Universidad Autónoma Metropolitana, as the third article we present, *An FPGA-based design for optical encoder fault detection and correction*, by RODRÍGUEZ-PONCE, Rafael, UGALDE-CABALLERO, Carlos Alberto and MOTA MUÑOZ, Francisco Gustavo, with affiliation at the Universidad Politécnica de Guanajuato, as fourth article we present, *Optomechatronics of laser micro-processing for manufacturing of optical waveguides*, by LOPEZ, Rubén, TELLEZ-LIMON, Ricardo a nd COELLO, Víctor, with secondment at the Center for Scientific Research and Education of Ensenada.

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Ultraviolet radiation quantification device for the prevention of Skin Cancer "Alert Skin"

Dispositivo cuantificador de radiación ultravioleta para la prevención de Cáncer de Piel "Alert Skin"

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Abstract

The objective of this article is the diffusion of technological innovation of the Ultraviolet Radiation Quantifier Device for the prevention of Skin Cancer. The method used in the investigation was: Quantitative, longitudinal, prospective, experimental. The viability of Design of a Ultraviolet Radiation Quantifier device was determined, the Ultraviolet Radiation Quantifier Device was made, the device was programmed to emit a signal to a mobile device, a platform compatible with the Android operating system was designed. Figure 1 The results obtained were: Ultraviolet Radiation sensor, Arduino and Bluetooh module were made, an application for mobile telephony was created called: Alert Skin for the prevention of harmful effects of Ultraviolet Radiation (Skin Cancer), with a total cost of 1332.00 pesos. Figure 2 Conclusions: Information and Communication Technologies can be used for preventive actions in Health, in this case, prevention of the harmful effects of Ultraviolet Radiation, such as Skin Cancer. Figure 3

Prevention, Cancer, Skin, Ultraviolet Radiation

Abstract

El objetivo del presente artículo es la difusión de innovación tecnológica del Dispositivo Cuantificador de la Radiación Ultravioleta para prevención de Cáncer de Piel. El método utilizado en la investigación fue: Cuantitativa, longitudinal, prospectiva, experimental. Se determinó la viabilidad de Diseño de un dispositivo Cuantificador de Radiación Ultravioleta, se realizó el Dispositivo Cuantificador de Radiación Ultravioleta, se programó el dispositivo para que emita una señal a un dispositivo móvil, se diseñó una plataforma compatible con sistema operativo Android. Figure 1-2. Los resultados obtenidos fueron: Se realizó un sensor de Radiación Ultravioleta, arduino y módulo Bluetooh, se creó una aplicación para telétono móvil llamada: Alert Skin para prevención de efectos nocivos de la Radiación Ultravioleta (Cáncer de Piel), con un costo total de 1332.00 pesos. Figure 2. Conclusiones: Se pueden utilizar tecnologías de la Información y de la Comunicación para acciones preventivas en Salud, en este caso, prevención de los efectos nocivos de la Radicación Ultravioleta, como Cáncer de Piel Figure 3.

Prevención, Cáncer, Piel, Radiación Ultravioleta

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Introduction

Chronic exposure to sunlight - especially the UVB component - accelerates skin aging and increases the risk of skin cancer. The environmental irradiation of said agent, hence the risk factor for photo-oxidative damage is increased, with long-term negative effects for aging, consequent decrease in the quality of life of patients and early appearance of skin cancer due to damage irreparable in DNA induced by ultraviolet light.

Reflection does not only occur at the surface of the stratum corneum, therefore at all interfaces a refractive index may occur. Dispersion occurs due to all the structural elements found in the skin, such as hair follicles, sebaceous glands and cellular components, as well as mitochondria and ribosomes. The remnant of UV light can, therefore, penetrate into the deeper layers of the skin. The penetration of UV light within the dermis exposes a variety of cells and structures, which depends in part on the thickness of the stratum corneum of the epidermis. The depth of penetration depends on the size of the wavelength. The same incident exposure of UVA and UVB radiation resulting from a high exposure can penetrate deeply.

The same incident exposure of UVA or UVB radiation resulting from a high exposure can penetrate deeply. The melanin particles are distributed in the stratum corneum depending on the type of skin, therefore six skin phototypes are considered according to the Fitzpatrick classification: Type I: Frequent and very easy sunburn. Pigmentation null or almost nil. Type II: Frequent and easy sunburn. Discrete pigmentation sometimes. Type III: Sunburn present. Light pigmentation. Type IV: Very rare or absent sunburn. Constant or intense pigmentation. Type V: Moderately pigmented skin. Type VI: Black skin.

The ability of the human skin to regenerate decreases with the passage of time and with exposure to UV light, therefore there is an increase in the fragility of it, with a reduction of skin cells and connective tissue collagen.

The damage induced to DNA by UVB radiation is the main factor that allows the induction of mutations and the beginning of the carcinogenic process.

Extrinsic cutaneous aging begins around 35 years of age, the sun is responsible for 90% of aesthetic lesions, attributed without any reason to physiological aging. Cutaneous aging is a complex biological phenomenon that affects the different components of the skin. There are intrinsic and extrinsic effects in the aging process.

In the skin there are changes at the level of the epidermis as melanocyte decline in approximately 15% per decade, doubling its density in photoexposed areas, there is also a decrease in Langerhans cells, decreasing sensitivity and immunity. In the dermis there is decreased collagen (1% per year) and decrease of fibroblasts with a progressive decrease of elastic tissue in the papillary dermis. Exposure to ultraviolet radiation initially produces an infiltration of neutrophils in the dermis, this infiltration is the key that activates the release of enzymes such as elastase and matrix metalloproteinase. There is also a reduction in the capacity of DNA regeneration. In addition, there is a reduction in the cutaneous microvasculature; Ultraviolet radiation, infrared rays and heat induce angiogenesis.

The clinical effects on the skin produced by ultraviolet radiation in chronic form are called photo-aging, ie the damage produced by the sun accelerating the aging of the skin. Table 1. This phenomenon is independent of the real aging of the skin, therefore it can be avoidable, and, therefore, in this investigation is considered knowledge about prevention using the range of frequency of use of sun protection measures in the last week. , as follows: (1 = never, 2 = rarely, 3 = less than half the time, 4 = more than half the time, 5 = almost all the time and 6 = always).

Hurt	Description	features
Type I (Medium)	Without wrinkles	Early photoaging Primary pigmentary changes media Minimal wrinkles Age of the patient between 20 and 30 years Minimal scarred acne
Type II (Moderate)	Wrinkles in movement	Early to moderate aging Senile lentigines visibly Keratosis palpable, not visible Lines parallel to the smile Age of the patient between 30 and 40 years Average acne scars

Type III (Advanced)	Wrinkles at rest	Advanced photoaging Discromía, telangiectasias Age of the patient 50 years or older Acne scars
Type IV (Severe)	Only wrinkles	Severe photoaging Malignant lesions No areas of normal skin Age of the patient between 60 and 70 years Severe acne scars

Table 1 Classification of Photoaging. Correlation between solar exposure practices and the degree of photodamage

It must be borne in mind that sometimes photoaging is accompanied by another effect of UVR which is photocarcinogenesis or the appearance of premalignant lesions: actinic keratosis, cutaneous horn, actinic cheilitis, Bowen's disease; or malignant lesions: basal cell carcinoma, squamous cell carcinoma, malignant melanoma on the skin.

In particular, it is important to consider that UV radiation is capable of being strongly absorbed by the conjugated double bonds of pyridines and pyridimines, causing the biomolecules to become reactive or ionizing them, to the extent that it can cause burns to the human skin or cause cancer. See "table 2".

Light type	Wavelength	Carcinogenicity
UVC	200-290	+++
UVB	290-320	++
UBA	320-400	+

Table 2 Characteristics of Ultraviolet Radiation and its relationship with Carcinogenicity. -: weak or no effect, +: slight effect; ++: moderate effect; +++: severe effect

UV solar radiation occurs with greater intensity in our latitudes during spring, summer and autumn between 11:00 and 15:00 hours, being particularly high in summer, although it decreases its intensity on cloudy days, while on the other hand the inclination with which the sunlight arrives during the winter months reduces its effects.

Considering that at higher altitudes on the coastline, the atmosphere is thinner, the WHO reports that for each 1000 m an increase in UV intensity between ten and twelve percent must be considered, so that at a height that oscillates about 2,300 meters as is the observed Valles Altos de Hidalgo, the intensity will reach between 23 and 27% higher compared to sea level.

The Polytechnic University of Pachuca is located in the High Valleys of Hidalgo at an altitude of 2330 meters above sea level, its climate is temperate dry, which causes scarce vegetation, which is why the solar radiation is intense due to its tropical latitude and height, is magnified by the reflection of bare floors and the materials walls and sidewalks. A research group is currently being set up with the objective of detecting and quantifying the possible dermatological damages that may occur in students and staff of the Institution. As a first stage of these investigations, the monthly quantification of ultraviolet radiation from 2011 to date is reported in this work.

Within the Mexican Republic, there is a history of similar studies, such as those carried out by the Department of Dermatology in the state of San Luis Potosí in 2003 [18], where the doses of ultra-violet radiation were reported in Mexican schoolchildren.

Exposure category	IUV interval
Low	<2
Moderate	3 a 5
High	6 a 7
Very high	8 a 10
Extremely High	11+

Table 3 Ultraviolet Radiation Indices

Ultraviolet Radiation Index	Protection Required
1-2	Does not need protection
3-7	You need protection, stay in the shade during the central hours of the day, use a sunscreen and cream and a hat.
8 or more	Avoid leaving during the central hours of the day. It is essential sunscreen, hat and stay in the shade.

Table 4 Recommendations for exposure to Ultraviolet Radiation

According to the monitoring carried out during the years 2011 to 2017, it was observed that the months in which the radiation indexes are above 8 which is considered high, up to 11 considered extremely high, occur between the months of March to October, while that during the months of November, the radiation does not show conditions that are considered potentially harmful to the skin of people.

It is important to point out that, in some years, as happened in 2011, during the months of July and August, they reached values above 14, which indicates extreme situations. The results show the intensities of ultraviolet radiation observed in the Altos de Hidalgo Valleys, particularly at the Polytechnic University of Pachuca, which is located within the municipality of Zempoala, Hidalgo. The fact that during the months of March to October exceeds values of 9 of the IUV during 207.7 days, being the value of 9 the one that is most frequently reached with 94.2 days, stands out.

It should be noted that the months of May, are those that have a greater number of days with radiation above 9, probably because there are no major cloudy in this month and the transit practically zenith of the sun to the line of the tropic of cancer (23 ° 27 '). While the month of June even though it has three days less under the IUV line, its intensity is usually the highest of the year and coincides with the solar approach and arrival at its zenith in the tropical line.

Frequently, the consequences of the effects of UV radiation are usually confused as derivatives of the atmospheric affectation of the ozone layer as occurs in the regions of the extreme south of the planet, however, what is observed in the present work, are local derived phenomena of latitude and height. It should be mentioned that despite the proximity of Mexico City with its serious pollution problems, it does not show the intensity reported here due to the protection generated by the frequent fogs during the summers.

On the other hand, it should be noted that the population of the Valleys Altos de Hidalgo should be subject to due precautions to avoid both burns and possible cases of cancer. Therefore, we consider it important that monitoring, as well as the dissemination of daily readings, be disclosed as a preventive process.

Skin cancer is one of the most common neoplasms, its incidence has increased in recent decades. The risk of a subject to develop skin cancer depends on constitutional and environmental factors. Constitutional factors include family history, light or red hair, multiple melanocytic nevi, sensitivity to sun exposure, among others. While ultraviolet (UV) radiation is a well-established environmental risk factor, and the most important.

Skin cancer doubles its incidence every 10 years. In Mexico there are about a thousand annual cases of skin cancer and because it is the largest organ of our body, the skin is susceptible to diseases caused by solar radiation.

The use of Information and Communication Technologies for the field of health in the prevention of deadly diseases such as skin cancer, which is the second most common type of cancer in Mexico.

Portable telephones suggested during the 80s of the 20th century, its diffusion is practically universal. Unlike the telephone cable used by landlines, mobile phones (or cell phones) use radio waves that provide the different mobile phone towers.

These mobile phones have auxiliary functions that depend on each model such as listening to music, radio, camera, etc.

The screens of mobile phones have a set of icons representing the most common utilities such as: contact list, calculator, etc.

Smartphones are mobile phones with more functions, the user can add different functionalities in the form of applications or programs. These applications because of their small size are often called "apps". 84% of Mexicans have a mobile device, 49% women and 51% men, in a percentage of 25% in the age range between 25 and 35 years. 78% use cellular and 39% Smartphone, with an average of possession of 2.

44% of Mexicans do not leave home without the cell phone, 60% never turn off the cell phone.

Users perceive an average of 4 advantages for the use of mobile devices, 77% of users have downloaded applications.

Methodology

Type of Research: Quantitative, longitudinal, prospective, experimental. The viability of Design of a Ultraviolet Radiation Quantifier device was determined, the Ultraviolet Radiation Quantifier Device was made, the device was programmed to emit a signal to a mobile device, a platform compatible with the Android operating system was designed.

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Results

An Ultraviolet Radiation sensor, Arduino and Bluetooh module was created, an application for mobile phone was created called: Alert Skin for the prevention of harmful effects of Ultraviolet Radiation (Skin Cancer), taking into account the photoprotection recommendations by skin type, height with respect to sea level (percentage), with a total cost of 1332.00 pesos. Figure 1 to 3.

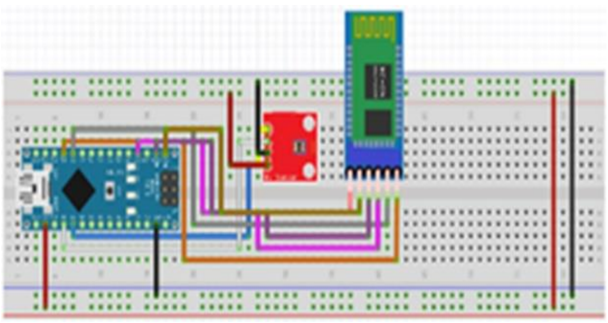

Figure 1 Design of the circuit board of the Ultraviolet Radiation Quantifier Device "Alert Skin"

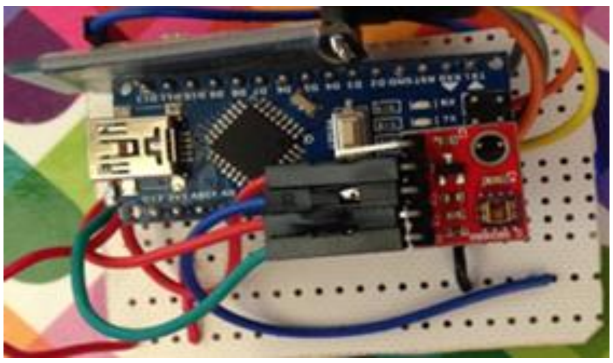

Figure 2 Installation of the circuit of the Ultraviolet Radiation Quantifier Device "Alert Skin"

Figure 3 Application "Alert Skin"

Conclusions

You can use information and communication technologies for preventive actions in health, in this case, prevention of the harmful effects of ultraviolet radiation, such as skin cancer.

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Article

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Optomechanical design and implementation with 3D printing

Diseño e implementación optomecánica con impresión en 3D

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Abstract

When carrying out the design and assembly of an experimental system (technological prototype), the optical engineer finds problems with the commercial availability of the optomechanical components and devices. The problem is that most of these elements are imported to Latin America or possibly for manufacturing specialized infrastructure and qualified personnel is required. In addition, existing designs are limited and the cost and time often delay implementation. Recently, in optomechanics, the possibility has arisen of designing, manufacturing and producing three-dimensional objects at a low cost from a CAD software and a 3D printer. Among the benefits found, it stands out that accelerates the process of implementation of an experimental system, has greater freedom in the design with respect to the commercial optical mounts, allows visualized scenarios of the mounts before being manufactured. In the same way there are disadvantages, because they do not have the same resistance, rigidity and life time that a metal or plastic emptied piece. In this paper we present both an analysis and an explanation of the process of design and development of various pieces that were implemented in the research laboratory.

Optical Mounts, 3D Printing, Optomechanical Design

Resumen

Al realizar el diseño y ensamble de un sistema experimental (prototipo tecnológico), el ingeniero óptico encuentra problemas con la disponibilidad comercial de los componentes y los dispositivos optomecánicos. La problemática radica en que la mayoría de estos elementos son importados por distribuidores de Latinoamérica o en su caso, para su fabricación se requiere infraestructura especializada y de personal calificado. Además, los diseños existentes son limitados y los costos y tiempos de entrega retardan muchas veces su implementación. Recientemente, en la optomecánica, ha surgido la posibilidad de diseñar, manufacturar y producir objetos tridimensionales a un costo bajo a partir de un software CAD y una impresora 3D. Entre los beneficios encontrados se destaca que acelera el proceso de implementación de un sistema experimental, tiene mayor libertad en el diseño con respecto a las monturas comerciales y permite visualizar prototipos de las monturas antes de ser fabricadas. Del mismo modo existen desventajas, pues no presentan la misma resistencia, rigidez y tiempo de vida útil que una pieza metálica o de plástico vaciado. En este trabajo presentamos tanto un análisis, como una explicación del proceso de diseño y puesta a punto de diversas piezas que fueron implementadas en el laboratorio de investigación.

Monturas Ópticas, Impresión 3D, Diseño Optomecánico

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Introduction

The limited allocation of resources for research and teaching have hindered the development of exact sciences and engineering in Latin America and developing countries. In particular, the instruments and developments where optical engineering intervenes, are of high costs for both the optical components, as for the mechanical frames, this is mainly due to the levels of measured tolerances from the wavelengths that are used in the system.

Many of these components are imported, which is why they are expensive for our economy. This is largely due to currency and tariff changes, which cause a considerable increase in their cost. While there are optomechanical elements that can be manufactured in local workshops, the configuration of the optical assemblies must have a high precision and as a result, some problems have arisen at the time of positioning and alignment with commercial products (lasers, diodes, detectors).

The characteristics of each experiment are unique and the products that are offered in the market are also limited, so they require a specific design and special manufacturing by numerical control equipment, which is not commonly accessed. Table 1 presents the various existing technologies for the manufacture of optomechanical parts.

The possibility of designing and manufacturing three-dimensional objects at a low cost and in a shorter time from a software and a 3D printer, offers the opportunity to develop custom parts designs and with particular specifications. Therefore, the option of using 3D printing in plastic as an alternative to the manufacture of metal parts made by casting, casting, forging, among others, or the acquisition of the same components at an obviously higher price, represents a very important viable option in the work of research and development of prototypes in optomechanics.

Process	Advantage	Disadvantages
Emptying plastic	• It is used for parts that must be reproducible. • If the mold is suitable the piece is obtained in a short time and the production cost is low. • Additives can be added to the plastic to improve qualities such as hardness, color, transparency, density, etc.	• You need to create a mold that contains the exterior details of the desired geometry; the complexity increases if holes are required or there are millimeter sections. • The piece is not homogeneous, it can contain air bubbles. • The mold can generate unwanted sections that will be evident until the piece has solidified. The mold, sometimes, is destroyed to extract the piece.
Metal machining	• The procedure can be performed for, in addition to metals, plastics, ceramics, wood or any solid material. • This process also refines flat surfaces and improves sections with rounding. • The cuts that are achieved with this technique are accurate.	• The machining machine is large. Its acquisition price is high compared to the other two methods. • For parts with great detail, the operator must perfectly control the movement of the material and the machine. • To obtain the piece, the metal must be larger than this. • There is waste of material and chips.
3d print	• The pieces that are obtained are reproducible, personalized and modifiable through the design software. • Plastic parts, ceramics, metals and even biomaterials can be printed. • The unit cost of production of the piece is low and can be manufactured quickly without the need for an operator to take care of the process.	• Pieces with millimeter sections are subject to the sensitivity of each printer. • The final piece contains remnants that must be removed by the user. • The surface finish of the piece, depending on the speed and temperature of the printer, can be rough or grooved. • The procedure must be carried out in an environment without air currents that cause the piece to contain dust particles, vibrations in the printer must be avoided because it can be decalibrated.

Table1 Comparison of technologies for the manufacture of optomechanical components
Source: Self Made

3D printing can be defined as a set of technologies that allow the manufacture of pieces with different geometries, because a CAD design software is used, which facilitates the manipulation of an element without needing to be tangible.

The program grants a wide variety of positioning with other parts thanks to its option of assembly, coupled with this, anyone with basic knowledge about the program can maneuver with the shape, tolerances, dimensions and thus project the need for assembly in a piece of support, retention, support, union, etc.

When you have the final sketch, the file must be saved with .STL extension, because it is the format that recognizes the printer software, this, commonly, is integrated with the machine and allows access to other types of parameters, for example: melting temperature of the material, thickness of the printing lines and the speed with which each layer will be deposited. It is at this point that the design process is completed.

When it comes time to manufacture the piece, you must also select the type of printer that will do the work; there are printers by photo-hardenable polymer, stereolithography, plastic extrusion and polymer injection printers. To choose the appropriate in general should be considered the following factors: printing speed, material, hardness and final finish desired in the pieces, as well as the prices of inputs.

In the case of optomechanics, we usually work with plastics, however, these devices can work with clays or metals. The most used thermoplastics are ABS (Acrylonitrile Butadiene Styrene) and PLA (Polylactic Acid), the preference of some will depend on the conditions of the experiment, the physical and chemical properties, if there is a possibility that it can undergo machining, its interaction with the light, heat, humidity, among others.

On the other hand, the hardness of the piece will depend on the thickness of each line and the printing speed. To obtain the designed piece, the printer melts the material, through an extruder, or the printer deposits the material to make the photo. The material is added layer after layer in a xyz plane on a base (bed) where "parts" of the piece that have no support "rest", finally a three-dimensional piece is obtained.

At the end of the manufacturing, the cleaning is carried out, final adjustment for the coupling of the piece in the experimental assembly and it is observed if it fulfills its function in the system.

Subsequently, both dimension and geometry errors are looked for to analyze if a modification and reprint is necessary, which is feasible because the design software allows the correction of the element and the printing cost is not excessive. If there is no other change, we continue with the integration of the elaborated piece to the experiment (or prototype) and the alignment of the same.

Development

When problems arise in the experimental assemblies or in the design of optical and optoelectronic prototypes, it is necessary to define if the optomechanical parts involved require a support or union piece.

To design the optomechanical parts to be manufactured, any CAD program can be used, in this work SolidWorks® is used. In this program the system of units is defined and the design of the piece that is regularly a support is proceeded.

This means that some element within the experimental setup needs to maintain a specific position and there is no existing commercial item that can be used for this purpose. The manufacture of the optomcanic component is done using a 3D printer.

A typical example of the disadvantages that can be solved is that of a suitable support for some source of lighting. In the low-power optical assemblies, LEDs are used as the source of light, either the standard 3 or 5 mm model, as well as sources with special characteristics such as the 1W LED that needs a suitable heatsink (Fig. 1), that there is no commercial model that adapts and supports the LED mounted on its heatsink.

Next, the design process for a mount is shown, which suits the conventional 1-inch ophthalmic. In general we proceed to consult the specification sheet of the device or measure its dimensions.

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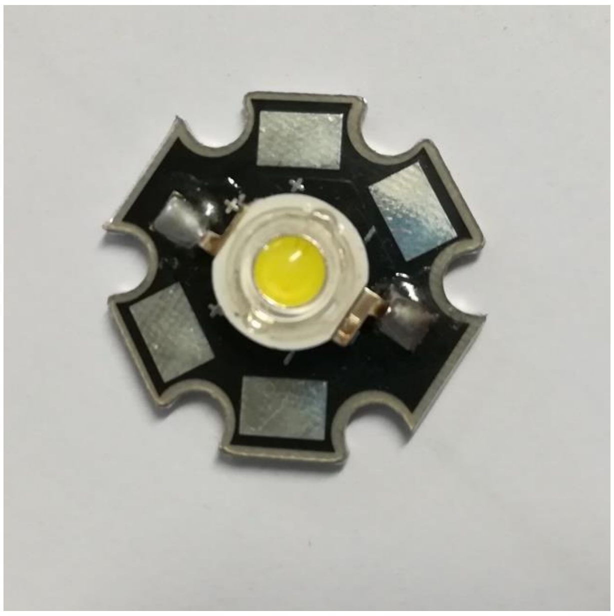

Figura 1 Power LED assembled with the heat sink
Source: Self Made

From the obtained dimensions, a sketch of the piece is established that is required in a three-dimensional plane with the specified dimensions. When working in a CAD program, it is possible to observe the different perspectives of the frame.

At the moment of designing a support, the dimensions of the element to be held must be considered, in this case a 1W LED, the possible remnants of the material, the expansion or contraction of the printing material and the minimum dimension that the 3D printer can work.

The printers to which we have access allow us a minimum dimension of 1.5 mm of thickness in the pieces, with which a support and a suitable hardness is obtained. The brands Makerbot®, Createbot®, Wanhao® and Creality® are the ones we have used with acceptable results, although in the market, there can be 3D printing systems with the same or better characteristics.

The second step is to extrude the piece to observe a three-dimensional sketch, verifying all the measurements and that the dimensions are homogeneous. It is analyzed if it is necessary to add or remove any sub-element such as: tabs or holes, add sections or holes for opresores screws, ensuring that the support complies with: fasten the component and fits the commercial optomechanical frame used in the system.

In Fig. 2, the consolidated sketch of the designed piece is shown, here we considered both the support of the piece and the space needed for the electrical connections of the LED. If there are no more modifications to the design, a map of views is created (the cross section and isometric), where the final dimensions of the object are observed, the assembly can even be presented with the external parts if its designs are available.

It is very convenient to make a backup of the file to make changes to the drawing if necessary, and store it in .STL format to be able to transfer it to the printing system.

The designs created in CAD design programs, consider a construction of solid models with exact measurements, so when creating the .STL files, these in principle do not fit one hundred percent with 3D printers. So you have to resort to mesh editing programs such as Autodesk Meshmixer® to verify the solidification, that is, you must ensure that there are no construction errors in the drawing (damage) that cause sections to be deleted in the printing process, as well as presenting a suitable mesh for printing. To avoid this, the .STL file is analyzed with the Autodesk Meshmixer® program.

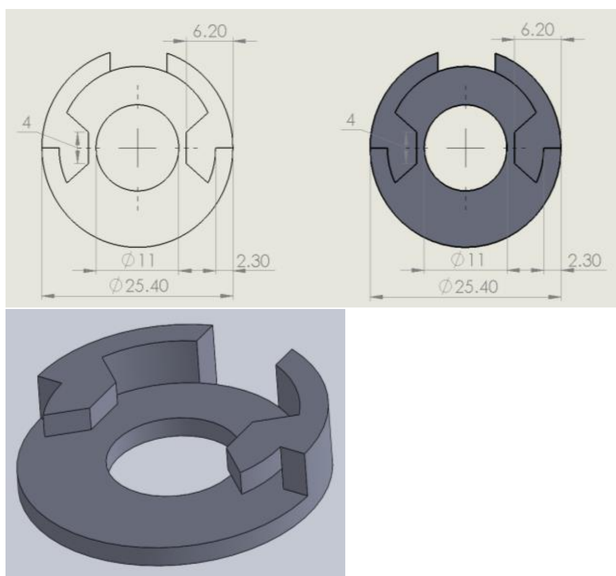

Figure 2 1W LED support (measures in mm)
Source: Self Made

Our experience has shown that it is preferable to modify the design in the software where it was originally designed. Although it can also be done in the mesh editor. In Fig. 3 a screen print of the mesh of the LED frame is presented.

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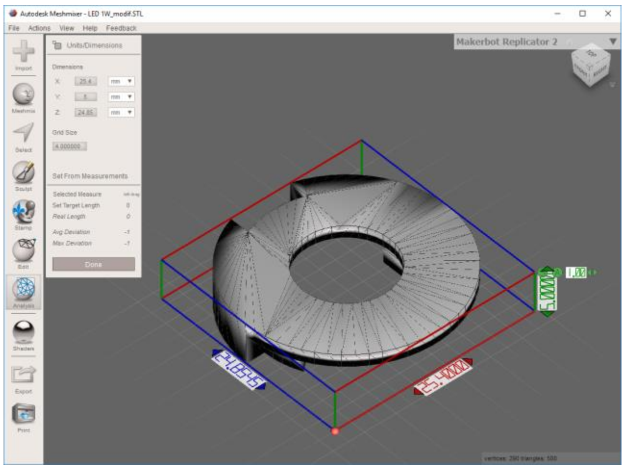

Figura 3 Review of dimensions in the MeshMixer program
Source: Self Made

The next step is to set the parameters of the printer, generally the ones that are modified are: printing speed, minimum thickness, density and printing temperature. Because the pieces that are regularly printed are not continuous, the software of each printer defines the trajectories and auxiliary supports, as shown in Figure 4.

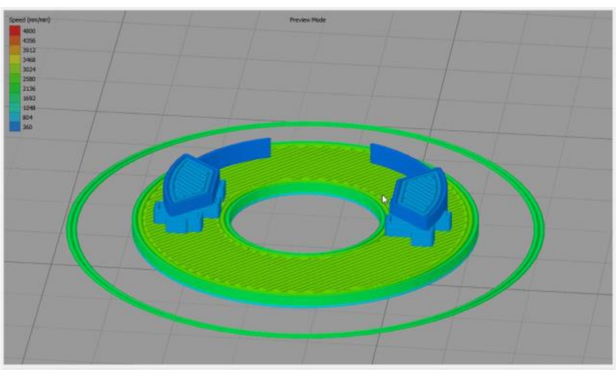

Figura 4 Scheme of the printing speed in the piece
Source: Self Made

While the printer works it is important to avoid vibrations or movements that may disturb the printing process. When this step is completed, the beds of the sections are removed and their air cooling finished. Due to the resolution of the printers, for a better finish the frames must be sanded.

Figura 5. 1W LED stand finished and mounted
Source: Self Made

After making the corresponding adjustments (remove auxiliary supports and unwanted material), the optomechanical mount is ready. Figure 5 shows the final result for our example. Figures 6, 7, 8 and 9 show examples of support for an LED laser, a mirror support to decentralize it, a base for coupling travel tables and a 45 ° support for a one-inch mirror, respectively. In summary, Table 2 describes the procedure necessary for the fabrication of an optomechanical frame by 3D printing.

1.	Identify the part that requires support, union, support, etc.
2.	Draw a sketch of the geometry that covers the need for support.
3.	Draw the required part in the CAD program. 3.1. Select the unit system. 3.2. Select the plane on which the piece will be worked (plant, elevation, etc.). 3.3. Draw the piece.
4.	Extrude the piece to generate a solid. Verify if holes are needed for screws, chamfer, rounding or some special feature for the design.
5.	Save the piece in .STL format and send the file to the meshing program for the analysis of dimensions, construction and meshing.
6.	Select printing speed, material temperature, thickness of each printing line, etc. in the printer software.
7.	Print the piece.
8.	Remove the supports generated by the printer, check the geometry and if necessary, clean the remnants of the material.
9.	Place the piece in the experimental assembly and confirm its purpose of subjection.
10.	Check if the piece that was printed needs corrections.

Table 2 Procedure for the manufacture of an optomechanical part with 3D printing
Source: Self Made

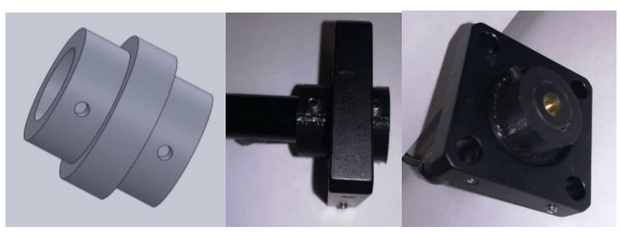

Figura 6 Support for diode laser
Source: Self Made

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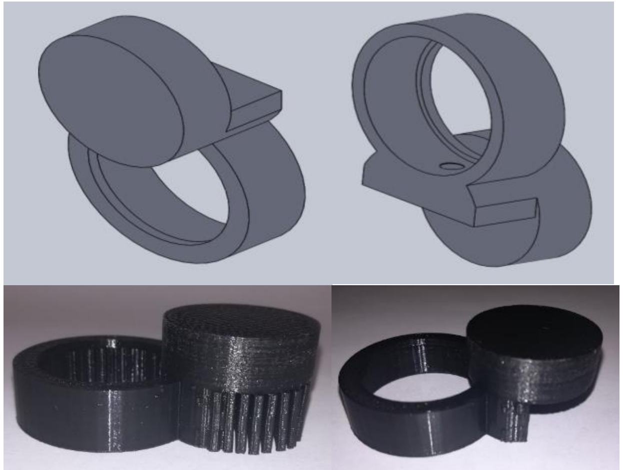

Figura 7 Mirror support
Source: Self Made

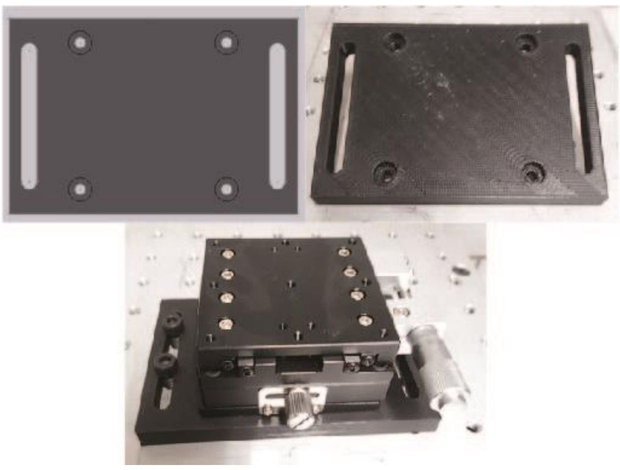

Figura 8. Base for coupling of sliding tables
Source: Self Made

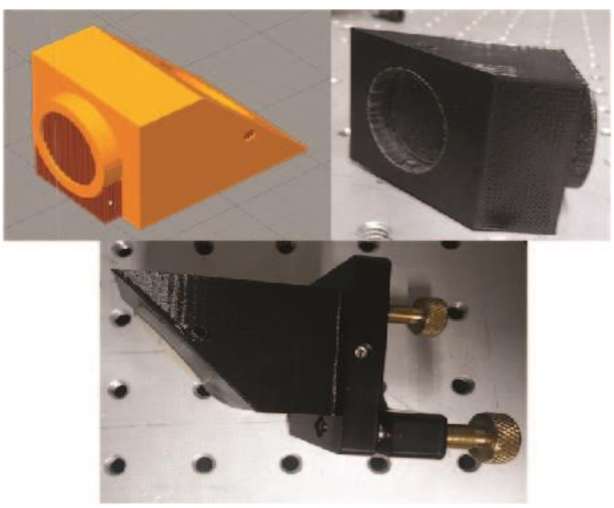

Figura 9. 45 ° support for one-inch mirror
Source: Self Made

The design time will depend on the geometric complexity and technical details of the optomechanical component, taking up to several days in the design, but if the piece is very simple it can take a couple of hours.

The printing time will depend mainly on the size and the working speed of the printer.

Thanks to the freedom with which you work in SolidWorks®, more complex geometries can be built, with space to place oppressive screws and although it has a limited life time and rigidity, the cost benefit of 3D printing makes this technology cost-effective the implementation of fixed experimental arrangements, design and testing of frames before manufacturing them with more expensive technologies, as well as for the construction of prototypes. It should be noted that, at the end of printing, the pieces usually have excess material and unwanted reliefs, so it is necessary to remove and sand the imperfections, this does not alter the function performed by the piece, the strength or density of this.

It should be clear that the disadvantages presented by the optomecanics designed and manufactured by 3D printing, limit its use in some situations, mainly those that present continuous adjustments for the use of oppressors or screws, as well as those that demand continuous stresses and stresses.

Due to the advantages presented, it can be applied in the realization of prototypes at high speed, with many degrees of freedom and low costs. In addition, in research laboratories they allow to substantially reduce costs and waiting time, mainly in developing nations. However, it is necessary to have trained personnel with sufficient experience for the proper design of these optomechanical components.

Conclusions

This paper shows some examples, advantages and disadvantages in the design and manufacture of optomechanical parts based on 3D printing. It also shows that this technology is one of the most promising inventions, being accessible in cost and management, so its inclusion in various fields, from industry to education, has been very promising.

The advantages of 3D printing in optomechanics are clear, the customization of the pieces allows them to become a common means of manufacturing them, the materials they use are, for the most part, recyclable or biodegradable, their use has been extended to Medical areas where organic tissue is used to create prostheses.

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It is important to mention that the optomechanical parts rarely need maintenance and their surface finish is suitable for the fixation of sensitive parts such as lenses or mirrors. Also, the time needed to obtain a piece with 3D printing is much less if it is contrasted with the time required when ordering the piece abroad and the cost of importing it. It must be taken into account that the useful life of these parts will depend on the technology and printing material. In some cases, it is an intermediate step to develop the molded metal or plastic frames.

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An FPGA-based design for optical encoder fault detection and correction

Diseño basado en FPGA para detección de fallas y corrección en encoders ópticos

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Abstract

High-accuracy industrial machines such as robotic manipulators and CNC machinery are highly dependent on optical encoders for achieving precise movements. These devices generate streams of pulses as feedback to the main controller for accurate electrical motor speed or position control. Due to high electrical disturbances caused by industrial machines, these digital pulses may get lost and cause significant current spikes and therefore damage on the controller's power circuitry. Several solutions have been proposed although these have been mainly restricted to fault detection at certain motor speeds. In this work, the authors propose a simple reconfigurable solution based on finite state machines which not only detects missing encoder pulses but can also regenerate them regardless of motor speed. Results were validated on computer simulations, as well as experimental implementation. The proposed architecture will be useful for researchers seeking a simple and precise method for optical encoder fault detection and pulse correction.

Quadrature encoder, Faulty pulse sensor, Electrical motor control

Resumen

Máquinas industriales de alta precisión, tales como manipuladores robóticos y maquinaria CNC son altamente dependientes de los encoders ópticos para lograr movimientos precisos. Estos dispositivos generan trenes de pulsos como retroalimentación al controlador principal para lograr un control exacto de la velocidad o posición de motores eléctricos. Debido a disturbios eléctricos en máquinas industriales, estos pulsos pueden perderse y con esto, causar transitorios de corriente que dañan la circuitería de potencia del controlador. Diversas soluciones han sido propuestas, aunque se limitan a simplemente detectar la falla en ciertos rangos de velocidad del motor. En este trabajo, los autores proponen una solución reconfigurable simple, con base en el uso de máquinas de estado finito, la cual no solo detecta la pérdida de pulsos en el encoder, sino que también puede regenerarlos independientemente de la velocidad del motor. Los resultados fueron validados en simulaciones de computadora y también en implementaciones experimentales. La arquitectura propuesta será útil para investigadores en busca de un método simple y preciso para detección de fallas en encoders y corrección de pulsos.

Encoder de cuadratura, Fallas sensor de pulsos, Control de motores eléctricos

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1. Introduction

Both robotic manipulators and CNC numerical control machines are an essential part of the automotive industrial machinery because they achieve highly repetitive and precise movements (Li-Ding y Jin, 2017). To execute the latter, these devices depend to a large extent on the use of optical encoders, which are mounted on each of the electric motors in order to quickly control their speed or position (Liu, 2002), (Belanger, Dobrovolny, Helmy y Zhang, 1998).

An optical decoder, more commonly called encoder (of its name in English), is an electromechanical device that generates one or more electric pulse trains based on any rotational movement of a motor; this allows the electronic controller to quickly determine its current speed or position of the arrow. The encoders are used in a wide variety of machines and can generate a wide range of pulses per revolution (ppr), starting from 100 ppr in printing equipment and reaching up to 10,000 ppr in industrial robots (Merry, Van de Molengraft y Steinbuch 2008).

Even though the encoders are extremely accurate and reliable, the train of pulses that they generate can be affected by external electromagnetic interference or disturbances in the electrical network, very common events in an industrial environment (Rothenhagen y Fuchs, 2008). When there is a loss of pulses in the line to the motor controller, a current transient occurs, which can cause damage to the electronic devices of the equipment. (Boggarpu y Kavanagh, 2010), (Alejandre y Artés, 2004), (Wang, Sun y Ooi, 2010). Even a high degree of vibration in the electric motor can create the same effect on the encoder pulses (López, Artés y Alejandre, 2011).

Various solutions have been proposed for the problem of loss of pulses in the encoders of industrial equipment, however, they have drawbacks of implementation or are simply limited to the detection of the fault. In the investigation of López and Artés (2012), a solution for the compensation of loss of pulses due to vibration is presented; this is based on Lissajous figures that was only validated by simulations and no experimental results are reported. In addition, the method is effective only in a certain range of engine speed.

Bourogaoui et. al (2015) presents a solution based on the application of the discrete wavelet transform, however, the system requires a high processing capacity in a personal computer and is limited only to detect the failure, without the possibility of compensating the loss of pulses, no matter how small.

In this work, the authors present a solution to the loss of pulses from a high resolution encoder, which is based on the use of finite state machines (FSM) in a low complexity digital architecture. Through this proposal, it is possible to quickly detect the loss of pulses, and also to generate them again, regardless of the speed at which the motor is working at that moment. In this way, user intervention is not required unless the failure is continuous or repetitive.

The proposal was implemented in an electronic card with low processing resources, which uses a field-reconfigurable gate array (FPGA, from the English Field Programmable Gate Array) Intel-Altera Cyclone V. The results were validated by computer simulations, as well as in experimental implementation using a 500 ppr encoder, in a DC motor working at a wide range of speeds; from 10 to 2500 revolutions per minute (rpm). The pulses were intentionally eliminated at different intervals and with different duration, without the controller registering on occasion, an increase in motor current.

2. Operation and construction of an optical encoder

An optical encoder is a specialized sensor, which is linked externally to the arrow of an electric motor. Its main function is to generate electrical pulses as the motor rotates and thus determine its speed, position and direction of rotation (Soloman, 2010).

Encoders can be classified, generally, as incremental and absolute; Incrementals generate one or more pulse trains with motor rotation. To determine the information of speed or position of its axis, a starting point is necessary and, from this, an electronic device keeps track of the number of pulses that were generated. In contrast, the absolute encoder, delivers a unique digital data for each position of the motor. In this way, it is not necessary to count the pulses since you have information of your radial location at any time.

Due to its simplicity of construction and low cost compared to the absolute encoder, the incremental is more used in high precision industrial machinery (Drury, 2009), which is why it is the central theme of this work.

The main operation of the optical encoder is based on the use of the light-emitting diode (LED). The encoder can have one or more LEDs, depending on how many pulse trains are required. There are single channel encoders; they are the simplest and most economical case, however, they apply only when the engine rotation is always in the same direction. When the direction of rotation is in both directions, two pulse channels are required (Figure 1), which are offset 90 °; this type of encoder is called incremental quadrature. In addition to the quadrature channels, it is possible that the encoder has a third output signal, called index (Z), which contains an electrical pulse for each complete revolution of the motor shaft. These signs can be seen in Figure 1.

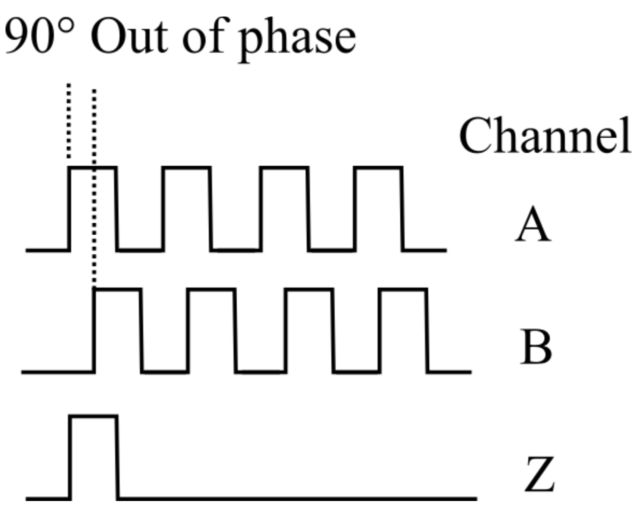


Figure 1 Output signals of an incremental quadrature encoder
Source: Self Made

Internally, the incremental encoder contains a transparent disk, which has a series of thin dark stripes along its circumference. This disk is fixed to the internal arrow of the encoder, which in turn is fixed to the arrow of the electric motor. The LEDs are placed on one side of the disk so that the beam of light emitted crosses the transparent disk and hits light receptors placed on the opposite side (Figure 2). When there is movement in the motor, each dark band of the disc momentarily blocks the beam of the LEDs, thus generating the pulses of each of the channels.

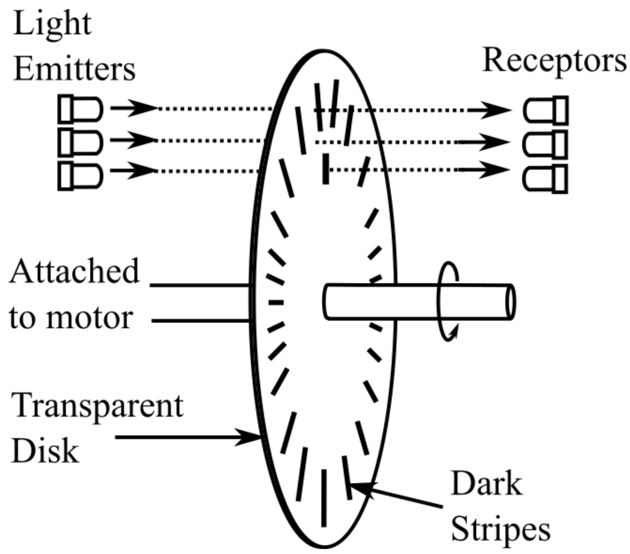


Figure 2 Internal construction of optical encoder
Source: Self Made

The number of slots per channel varies according to the resolution required in the encoder. There are low resolution encoders that can have 100 fringes in each quadrature channel; These devices are normally used in equipment whose mobile parts do not require high precision. An example is in printing equipment, in which the print head must move to a specific position to print the correct data. On the other hand, there is industrial machinery whose movements can be of the order of microns, as it is in CNC machining centers.

In this case, the optical encoders used can have up to 10,000 slots per channel, thus being able to generate a signal of pulses of very high frequency in each rotation. For this reason, the high resolution encoders are perfectly sealed to avoid the intrusion of dust, metal filings or liquids normally present in an industrial environment. In addition, the arrow of the device must be very well aligned and balanced, with bearings sealed so that, when the arrow is rotated, there is no minimum vibration between the components or even friction between the encoded disk and the emitters / receivers of the beam light.

3. Failures in optical encoders

The optical encoder is a highly reliable and long-lasting device, however, there are faults of different types that may occur. When this happens, there is an increase in the current of the power stage of the motor motion controller (Rothenhagen y Fuchs, 2008).

This is because, when the controller stops receiving pulses, it interprets it as an engine stop due to lack of power. Therefore, it increases the current to increase the torque in order to keep it moving. If there is still no movement, the current will be able to grow very quickly, damaging your electronic circuitry. In this way, it is important that the pulse train is not interrupted when there is a movement command from the controller.

One of the first faults in encoders may be due to vibration (López, Artés and Alejandre, 2011) or due to electrical disturbances in the power supply network. (Bourogaoui et. al, 2015). Whether due to defects in manufacturing or use, if there is a high degree of vibration in the device or if there are transients in the power supply, it is possible that there are losses of pulses or a deformation of them. This is because you can lose the square between the channels or if the emitters / receivers of light present friction against the encoded disc.

Another cause of failure is due to mechanical sensor problems (Bourogaoui et. al, 2015). Due to the high resolution of precision encoders, these are perfectly sealed to prevent the entry of external contaminants. However, due to the use and high speed of the shaft, over time the seals of the device suffer wear, which can allow the entry of oils, dust or even moisture. When deposited on the coded disk or on the light receivers, this causes intermittent losses of pulses in the quadrature channels.

4. Proposed solution

This paper presents a digital system implemented in an FPGA, which continuously monitors each of the pulse channels of the incremental encoder. The crucial information for the system is the duration of the sensor pulses and the quadrature between the channels. In this way, when one or several of them are lost, the pulse is reconstructed at the precise moment, so that the controller does not record it. Only in the case of a total loss of sensor pulses, the system sends an alarm signal and stops the process.

The design of the architecture is based on the use of FSM, because they allow the operation of synchronous circuits at high speed and with great efficiency, in systems with limited digital processing resources (Pedroni, 2013), (Tiwari y Tomko, 2005).

The proposed digital architecture is divided into two main modules, identified as the measurement module (MED) and the regeneration module (REG), and are shown in Figure 3.

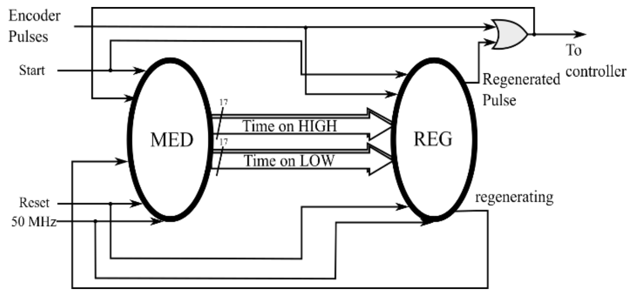


Figure 3 Block diagram of the proposed system
Source: Self Made

The MED function consists of constantly measuring the duration of time in high and low pulses of the encoder. These times are stored at each signal transition, in 17-bit registers. The function of the REG module is to regenerate one or several lost pulses, with the same time and square. Because the system uses a 50 MHz clock, it is possible to check the pulse signal every 60 ns, regardless of whether the motor works at different speed ranges or with high or low resolution encoders.

5. Pulse measurement module (MED)

In order for the system to work optimally, it is first necessary to have information about the pulses coming from the encoder. This signal is a train of square pulses that go to a high level and then to a low level constantly. The time in high or low is very important because it gives us an idea of the current operation of the motor. When it starts to work, the duration of the pulses is high, since the rotation starts relatively slowly and then acquires speed, where the pulses become increasingly narrow. In addition, the engine does not always work at the same speed so the pulse width changes constantly, however, it does so gradually.

To carry out the precise measurement of time, the MED module has a high speed state machine, which detects the change of flank in the channels; in each change, it enables 17-bit counters, which work at a frequency of 50 MHz and can detect changes in pulse width in less than 60 ns.

On each flank of the pulse, the duration of the level is passed to asynchronous registers, in which the information is retained to be compared (in the REG module) with the information of the previous pulse. In this way, if the difference is greater than a tolerance programmed by the user, it means that there was a loss of pulse. The architecture of the MED module is shown in Figure 4.

To avoid entertaining the FSM in any other activity, the only function of the MED module is the measurement of high and low times. Decision making about whether a missing pulse occurred is carried out in the REG module.

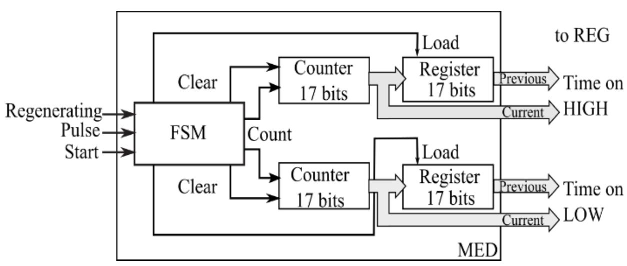


Figure 4 Architecture of the MED module
Source: Self Made

It should be noted that MED can receive two types of pulses: the first are pulses coming directly from the motor encoder. In this particular case, it continuously measures the duration of the pulses and is stored in registers. This information is also sent to the REG module, in order that the regenerated pulses are identical to the last pulse received.

Another type of pulse that can receive its input, are the pulses that were already regenerated by the REG module before the detection of a lack of pulses. In this situation, it carries out the measurement of the pulses, however, it does not save the new information in the registers, because it is a temporary pulse. Once it has been detected that the original signal of the encoder has already been restored, until then it returns to its function of measuring and saving.

6. Pulse regeneration module (REG)

To determine if there was a missing pulse, the high and low time information coming from the MED module is used. With this information and based on the tolerance time provided by the user, an FSM of 8 states determines if there was a missing pulse or the engine is only changing speed.

Even if the motor is working at the same speed, the pulses of the encoder do not always have identical times, so it is very important to provide a small tolerance. This tolerance will depend on the speed ranges at which the motor will work and the encoder resolution. The algorithmic state diagram of the FSM is shown in Figure 5 and is described below.

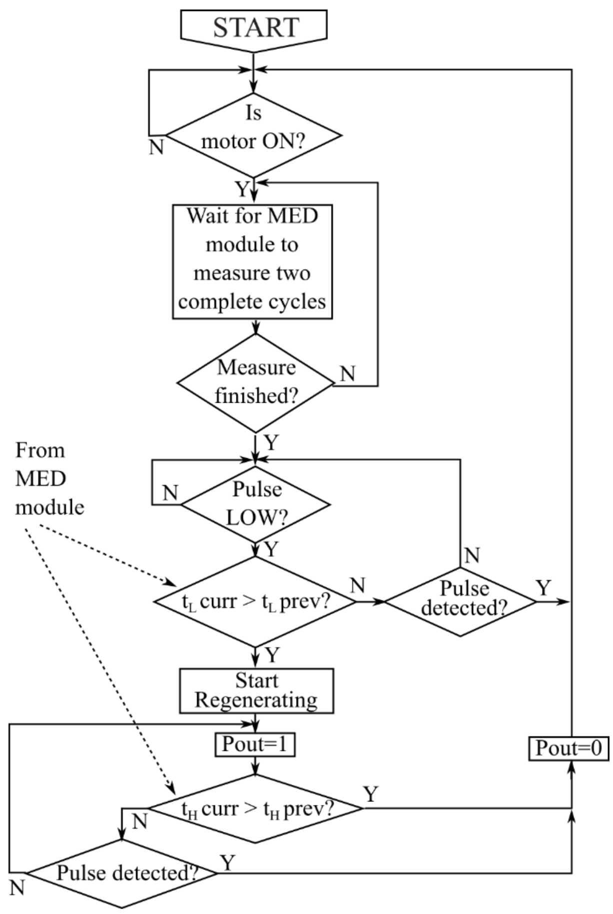


Figure 5 Algorithmic diagram of the FSM of the REG module
Source: Self Made

The process starts when a command is received to start the engine. In this case, it is necessary to first measure the width of the pulses, to have an initial reference data. In this way, it is first identified if it is a high or low pulse, and then it passes to a pair of empty states where the REG module does nothing, however, it allows the MED module to carry out the corresponding measurements of the pulses of the encoder and store them in synchronous registers. Immediately wait until a low level is present, since it is in this part of the signal that the lack of a pulse would be observed. Once the low level is identified, start comparing the time against the time of the low level in the record. If a high pulse is presented in the expected time, the next low level is expected again.

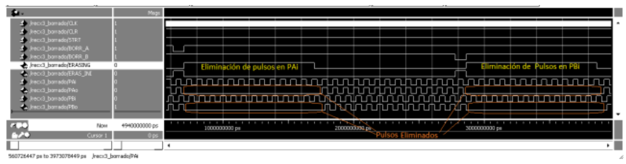
Otherwise, it means that there is a missing pulse and goes to the regeneration stage where it sends a high level to the output, while its time is compared to the last time stored in the MED module record. Once the time has elapsed or if the pulse train of the encoder is reset, the FSM exits the state of pulse reconstruction, verifies that the start command remains active and the process is repeated indefinitely.

7. Simulation Results

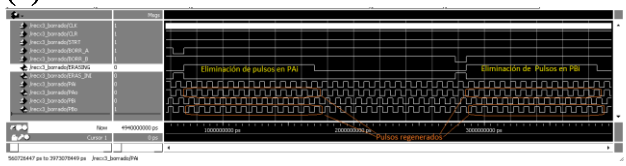
The hardware encoding on the FPGA card was made using the VHDL language, using the Intel-Altera Quartus Prime Lite platform. For the electronic simulation, Modelsim Altera-Edition was used, in which multiple tests were made with two quadrature channels at different frequencies and pulse widths, to simulate different resolution encoders working at different speeds. In addition, a circuit was designed separately in the FPGA, which allows to carry out the erase of pulses at different times. In this way, when receiving an external pulse by the user, it can block any of the quadrature signals by programmable intervals ranging from microseconds to milliseconds. This in order to force the erasure of pulses and, at that moment, verify that the pulse or its square are not lost.

In the first simulation shown in Figure 6 (a), quadrature signals (PAi and PBi) are included for a 500 ppr encoder rotating at 1500 rpm. In this case, the erase time was set to 1 ms. To initiate the elimination of pulses, a signal is sent in low (BORR_A o BORR_B). A signal in high (ERASING) indicates that the period of elimination of pulses is in process. It can be seen that the quadrature signals (PA0 and PB0) of output are completely eliminated when the pulse regeneration system is disabled.

On the other hand, in Figure 6 (b) once the proposed system has been enabled, it can be observed that the quadrature signals (PA0 and PB0) of output remain identical to the input signals and have not suffered any loss or loss of squareness.



(a)



(b)

Figure 6 Computer simulation using Modelsim for an encoder of 500 ppr and a rotation speed of 1500 rpms where the pulse output (a) is shown with the proposed system deactivated, and (b) with the regeneration system enabled. Both signals had a pulse elimination time of 1 m
Source: Self Made

Simulations were carried out for different resolutions and rotation speeds, presenting all signals identical to the input ones, thus giving validity to the proposed architecture.

8. Experimental results

For the experimental validation, a direct current motor with brushes and a quadrature encoder of 500 ppr were used. The engine has a Pololu VNH5019 sensor, which allows monitoring the behavior of its current. Both the pulse signals of the encoder and the current signal are displayed in the LabVIEW © software through the use of a myRIO-1900 module from National Instruments.

The digital architecture of the proposed system was implemented in the Intel-Altera DE1-SoC development card, which uses the FPGA Cyclone V 5CSEMA5F31C6. The complete system is shown in Figure 7.

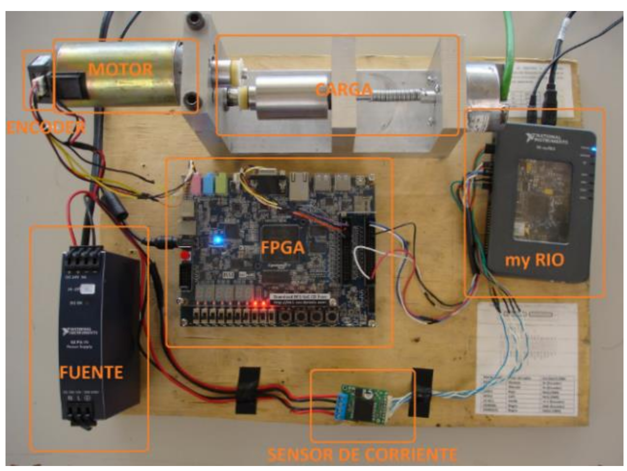


Figure 7 Complete implementation of the proposed system on the DE1-SoC card
Source: Self Made

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As was done in the validation by simulation, tests were carried out at different engine speeds, with ranges from 100 to 2500 rpm. The pulse channels of the encoder pass through the FPGA card and then continue to the myRIO module; this in order to be able to eliminate the pulses with different periods, which ranged from 100 μs to 100 ms, depending on the speed of the motor.

In Figure 8 (a), the signals for a test at 1000 rpm can be observed using periods of 7 ms pulses. In principle the engine is made to work and a pulse is sent manually to initiate the elimination of pulses of channel A for the aforementioned time. During this period, the ERASING signal remains high to indicate that the system is blocking the pulses of channel A, while the REG module is regenerating them and sending them to the motor controller.

Figure 8 (b) shows the behavior of the current when the pulses are eliminated and the regeneration system is disabled. In this case, the motor current rose to more than double its nominal value because no encoder pulses were recorded. Once the system is enabled, it is observed in Figure 8 (c) how the current stays within its normal range during the erase time.

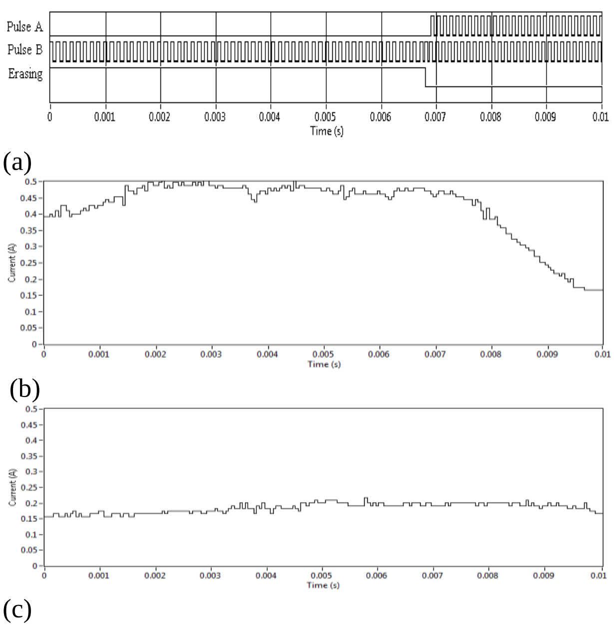

Figure 8 Experimental results observed in National Instruments LabVIEW © software, (a) when encoder pulses from channel A are eliminated, the behavior of the motor current (b) with the regeneration system disabled is observed, and then (c) with the system enabled
Source: Self Made

9. Conclusion

In this work, the authors have presented a reconfigurable system for detection and regeneration of lost pulses in incremental quadrature encoders. This digital architecture in FPGA based on finite state machines, allows a quick compensation of this type of failure regardless of the working range of the electric motor or the resolution of this type of transducer. Through computer simulations and experimental results, it was possible to verify that the system allows detecting and correcting the pulse problem in time, without the characteristic increase in motor current.

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Optomechatronics of laser micro-processing for manufacturing of optical waveguides

Optomecatrónica de micro-procesamiento láser para fabricación de guías de onda ópticas

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Abstract

A prototype optomechatronics system for laser engraving of multimodal optical waveguides is presented herein. This system is based on the optomechanics of micro-positioning used for the optical disk drives. The development consists of a human-machine interface, a CO_2 laser that selectively fuses the substrate, and a two-stage linear micro-positioning system. The first stage uses a servomotor setup that provides a linear displacement of 10mm when is applied a 180° rotation; the second stage is based on a galvanometer, providing a linear displacement of 2mm when varying the voltage at its terminals in a range of ±10V with an 8 bits digital to analog converter. For an optical power density of ~7.5W/mm^2, the results show an average waveguide width of 320µm on polymethylmethacrylate substrates and 270µm for glass substrates. These waveguides could be used in the development of photonic biosensors.

Optomechatronics, Waveguides, CO_2 laser

Resumen

Se presenta un sistema optomecatrónico prototipo para grabado láser de guías de onda ópticas. Este sistema está basado en la optomecánica de micro-posicionamiento empleado en las unidades de disco óptico. El desarrollo está constituido por una interface hombre máquina, un láser de CO_2 que funde selectivamente el sustrato y un sistema de micro-posicionamiento lineal de dos etapas. La primera plataforma utiliza un arreglo de servomotor (piñón-cremallera) que proporciona un desplazamiento lineal de 10mm al aplicar una rotación de 180°; la segunda está basada en un galvanómetro que proporciona un desplazamiento lineal de 2mm al variar el voltaje en sus terminales en un intervalo de ±10V con un convertidor digital analógico de 8 bits. Para una densidad de potencia óptica de ~7.5W/mm^2, los resultados arrojan un ancho promedio en la guía de onda de 320µm sobre sustratos de polimetilmetacrilato y de 270µm para sustratos de vidrio. Estas guías de onda podrán ser empleadas para el desarrollo de biosensores fotónicos.

Optomecatrónica, Guías de onda, Láser de CO_2

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Introduction

In the current environment it is difficult to imagine any technology that does not involve light, whether emitted by a source or received by a detector. Optics is precisely the science that studies the behavior of light and is immersed in areas such as electronics, medicine and communications. The fact that light is and tends to be in even more technologies is because of its speed and because it has no mechanical contact with the body in which it affects.

In this sense, mechatronics, when merged with optics, gives rise to optomechatronics (Cho, 2002), a branch of engineering that automatically controls the movements of devices that detect or emit light, such as laser processing systems (Cho, 2005). Another engineering that uses light is biomedical for biosensing applications (clinical diagnosis), where one of the ultimate goals is the development of integrated nanophotonic circuits for the simultaneous detection of multiple pathological agents present in fluids (lab-on-a-chip).

One of the fundamental components for these biosensors are the optical waveguides, which allow the propagation of light between two points (Čižmár, 2011). Figure 1 shows the schematic of a nanophotonic biosensor which is composed of the substrate that supports a metal nanostructure where the interaction of light with fluids and the waveguide embedded in the substrate occurs. The fundamentals of optics are of great relevance for technological areas such as communications, medicine, industry, etc. and mechatronics is not the exception. This is because the light has properties that distinguish between them their speed (3x10-8km / s), does not produce mechanical efforts and with it can store enormous amounts of information.

One way to develop an embedded waveguide is by locally modifying the refractive index of a substrate following a certain pattern of lines (Alvarado, 2013). For this reason, its manufacture requires appropriate methods and tools. The most used methods for this are the reactive ion exchange (using masks recorded by photolithography), the deposition by flame hydrolysis (FHD) and by laser marking (Aggarwal, 1984). For this last case, systems that can perform micro-positioning for the writing of the guides are required.

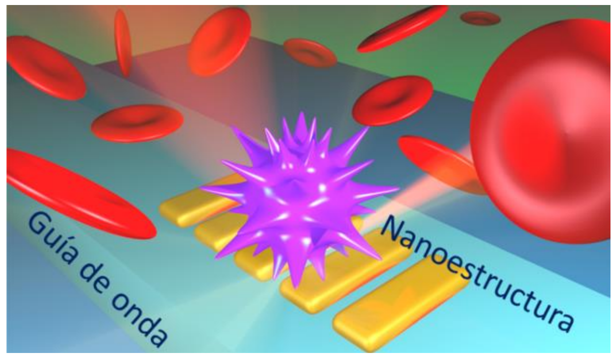

Figure 1 Schematic of a nanophotonic biosensor with the waveguide embedded in the substrate
Source: Self Made

In this sense, the nano-electromechanical (NEMS) and micro-electromechanical (MEMS) systems have been used for the manufacture of these elements at nano- and mico-metric scales (Bao, 2005). In the most used technologies for N / MEMS actuators, the micro motor with electrostatic steps and cantilever plates is found, leaving the nano-positioning to the technology of piezoelectric plates. (Hwu, 2006). There is a wide market of distributors of micro-positioning systems, but the clearest disadvantage is the initial investment to acquire these devices.

A low-cost alternative is the technology used for reading and writing optical discs (practically discontinued), since it has a sophisticated optomechatronic system that has a precision and fine positioning scale. (Wilkander, 1992). These systems are able to read repeatedly and without error the tracks (pits) of the compact discs, which are separated distances in the order of µm or nm depending on the format (Taylor, 1998). Taking into account the wide use of micro and nano positioning systems in the area of experimental optics, in this work a micro-positioning system based on the optomechatronics of the optical disc unit for the laser writing of guides was implemented wave.

Optomechatronics for laser micro-processing

The development of this project consists of two main stages: the development of a mechatronic system for the micro-positioning of the substrates based on the use of an optical disc reader, and the development of a control system for turning on and off the laser used for writing the waveguides.

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Mechatronic system

Optical disc (DO) drives for CD, DVD or BD disc playback have the same operating principle (Stan, 2013). Its positioning resolution depends on the wavelength of the laser used for reading. The optomechatronic used by these systems consists of two stages.

The first provides a uniaxial motion with stepper motor for a coarse movement of the reading head by means of an arrangement of reducing gears, while the second uses a galvanometric system for micro and nano metric displacement of the lens.

For this project, the thick displacement stage did not have significant changes focusing on the galvanometric actuator. Its displacement depends on the voltage induced between one of the two pairs of terminals with which the electromechanical assembly has.

Each pair of terminals are connected to an inductor that, by the passage of a controlled current, generates an electromagnetic field which induces two possible movements, the linear displacement and the movement to focus the lens, the first being the employee in this project.

Figure 2 shows the diagram of the elements that provide the movement of the galvanometric micro-positioner (where the objective lens is mounted), which are: (1) pairs of copper wires, which provide support for the positioner to be discontinued.

They show deflection due to the interaction of the electromagnetic field and permanent magnets. (2) - (3) pair of terminals of each support wire in which the control voltage is induced, either for the linear or focus movement of the lens; (4) permanent magnets to provide a permanent magnetic field that interacts with the electromagnetic fields caused by the passage of current in the inductors; (5) career stops to limit the displacement of the lens, (6) inductors to generate an electromagnetic field by inducing voltage at the terminals and (7) the objective lens.

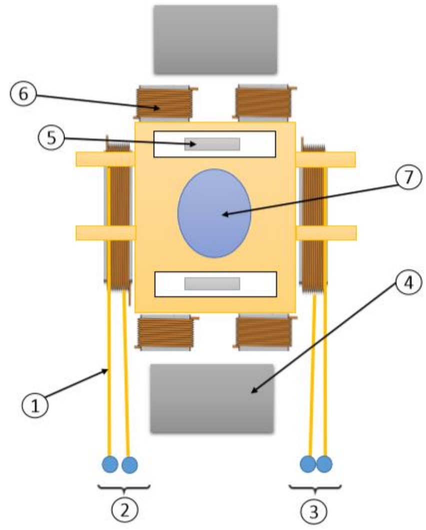

Figure 2 Schematic of a galvanometric actuator
Source: Self Made

The normal actuator position is in the center of the structure. To displace it, a bipolar voltage must be applied. If there is only one unipolar voltage signal to feed the galvanometric system, a unipolar to bipolar signal conditioning circuit can be used (Duke, 2013) as shown in Figure 3. This circuit uses an operational amplifier with negative feedback and three resistors in a modified adder amplifier configuration to generate high voltage bipolar outputs from a unipolar Digital Analog Converter (DAC).

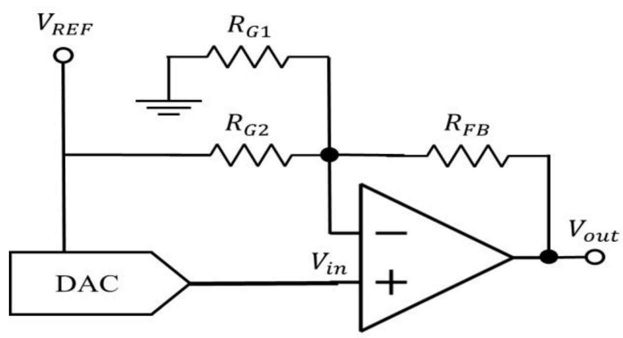

Figure 3 Circuit conditioning of unipolar signal to bipolar
Source: Self Made

The CD transfer function of the circuit, given in equation (1), is based on the ratio of the R_{FB} feedback resistor and the gain adjustment resistors R_{G1} and R_{G2}:

$$V_{out} = \left(1 + \frac{R_{FB}}{R_{G2}} + \frac{R_{FB}}{R_{G1}}\right) V_{in} - \frac{R_{FB}}{R_{G2}} V_{REF}. \qquad (1)$$

When the output of the DAC ($V_{DAC} = V_{in}$) is 0V, the inverting input is a virtual ground so that no current flows through R_{G1}, making the circuit operate as an inverting amplifier with gain equal to R_{FB}/R_{G2}.

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When the output of the DAC is V_{REF}, the potential of the inverting input is equal to V_{REF} so that no current flows through R_{G2}, causing the circuit to operate as a non-inverting amplifier with gain equal to $(1 + R_{FB} / R_{G1})$. For the calculation of the resistive components in case the full scale of V_{out} is ± $2V_{REF}$ it is necessary to:

$$R_{G1} = R_{FB}, \qquad (2)$$

$$R_{G2} = R_{FB}/2. \qquad (3)$$

Optical system

The laser manufacturing process of waveguides embedded in substrates consists of engraving lines on a substrate by melting the material. This modifies the refractive index in the irradiated area. For this the parameters that have to be considered in the laser process are the optical power density, and the speed of movement as a function of the substrate material.

The power density is defined as the power P that affects an area A and is given by the expression:

$$DO = \frac{P}{A} \qquad (4)$$

The area is defined by the expression $A=\pi(d/2)^2$ where the diameter d is provided by the laser equipment manufacturer. This power density can be increased by placing a lens in the laser path, which can theoretically focus the beam diameter up to half the wavelength (λ) emitted by the laser (diffraction limit), determining the theoretical limit of the width of our waveguide.

Experimental arrangement

For the experimental tests, the arrangement shown in figure 4 was implemented. The assembly includes the micro-positioning galvanometric system (1), the servo motor for pre-positioning (2) and the CO_2 laser with λ = 10.64μm (3), all controlled by computer. Within the optical arrangement used is a mirror at 45 ° (4), which reflects the laser beam towards the target, and it passes through a lens (5) where theoretically the spot is reduced to λ / 2., For the tests of etching, different substrates (6) were used, keeping the average optical power and the speed of displacement fixed.

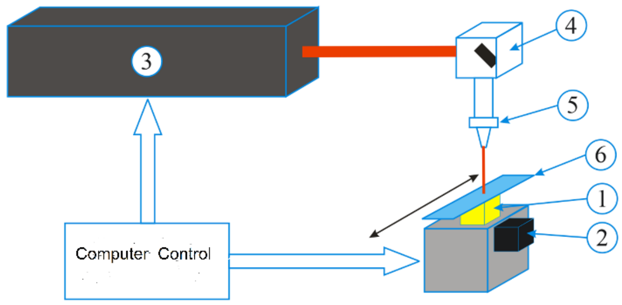

Figure 4 Schematic of the experimental arrangement
Source: self made

Results

Optomechatronics

For the galvanometer used, it was found that for an input voltage of 1.53V and a current demand of 0.4A (3.9Ω), the head makes contact with one of its stroke stops approximately 1mm away from the origin, ie, to have a total displacement of 2mm, requires a bipolar voltage of ± 1.53V. To decrease the signal-to-noise ratio of the control voltage it was increased to ± 10V and a series resistor of 20Ω was added to maintain the current ratio.

To control the movement of the galvanometer, a National Instruments USB-6008 data acquisition card was used that has digital-to-analog converters (8 bits) on a scale of 0V to 5V. To convert this unipolar control output to a bipolar ± 10V output, the circuit of Figure 3 was constructed, using an LM3886 power operational amplifier. The calculation of the components based on a feedback resistance R_{FB}=20KΩ resulted in R_{G1}=20KΩ and R_{G2}=10KΩ, having an error of ± 0.2V in the output voltage.

The control of gross movement of the detector head did not have significant changes. For this purpose, a rack-and-pinion servomotor arrangement was used, which, by applying a 180 ° rotation, provided a linear displacement of 10mm. Figure 5 shows a laser processing image of a substrate with the optomechatronics developed.

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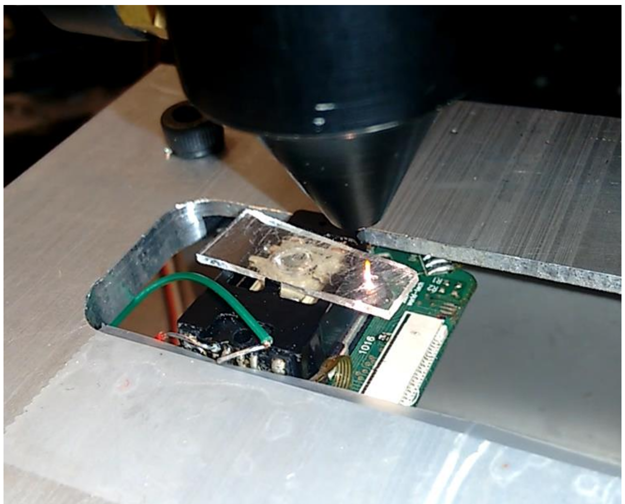

Figure 5 Laser processing of a substrate with the optomechatronics developed
Source: Self Made

The man-machine interface was developed using LabVIEW software, whose front panel is shown in Figure 6. The initial position field controls the linear displacement of the read head. Knowing that the maximum displacement is approximately 2000µm, the start of the processing can be done along those 2000µm. Due to the sampling frequency of the NI USB6008 card (10KS / s), there is a minimum allowed exposure time (time it takes to manufacture the guide) which is a function of the length of the waveguide to be manufactured (0 to 2000µm). If you want to respect the theoretical resolution provided by the DAC of the card, you must select a time greater than or equal to the minimum exposure time.

Figure 6 Man machine interface developed in LabVIEW
Source: Self Made

Manufacturing of guides

For the writing of the waveguides, a 150K DIMOND laser was used by Coherent Inc. This laser emits an electromagnetic transverse mode with Gaussian profile (TEM00) and a maximum optical power of 150W in quasi continuous operation.

The manufacturer indicates a beam diameter of approximately 7mm. The power used in the laser writing was 0.6W that corresponds to an optical density DO≈15mW / mm2 during the process. Below are two of the results obtained from engraving the waveguides. The first one was made on polymethylmethacrylate substrate (Figure 7) and the second on a glass substrate (Figure 8). These images were taken with a commercial optical microscope. The diameter measurement of the guide was made by means of a reference standard, obtaining for the acrylic an approximate diameter of 320µm and for the glass an approximate diameter of 270µm. It can be highlighted from these photographs that in the direction of movement (vertical) the steps of movement are imperceptible even at this scale.

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Ing. Xavier Eduardo García Sánchez for his collaboration in the development of mechatronics.

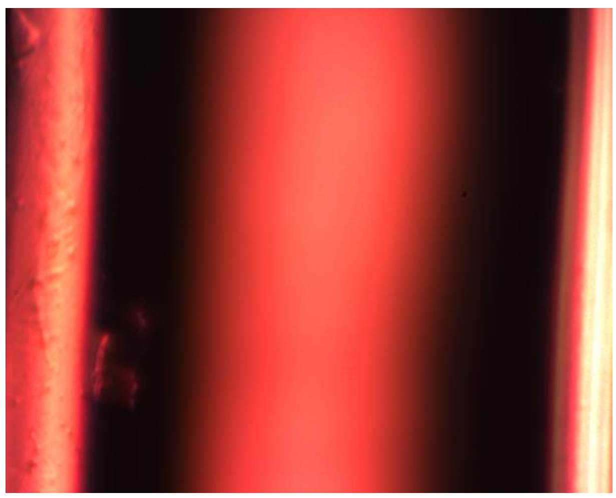

Figure 7 Wave guide written in polymethyl methacrylate
Source: Self Made

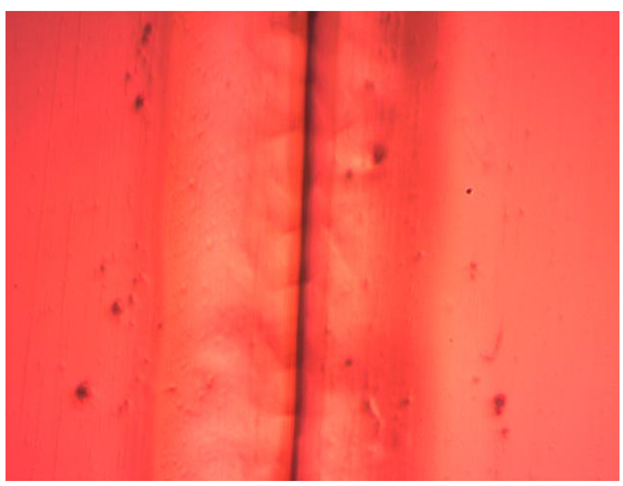

Figure 8 Wave guide written in glass
Source: Self Made

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Conclusions

This work has shown a practical and innovative use based on the sophisticated technology but at the same time underestimated by the optical disc units. The galvanometric system provided a linear displacement of 2mm by varying the voltage at its terminals in a range of ± 10V with an 8-bit analog digital converter. For an optical power density of ~ 7.5W / mm2, the results showed an average waveguide width of ~ 320μm on polymethylmethacrylate substrates and ~ 270μm for glass substrates. These preliminary results will allow the optimization of waveguide writing processes in different substrates that may be used in the development of integrated photonic biosensors.

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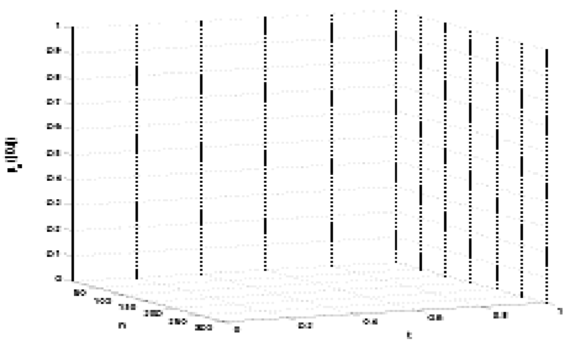

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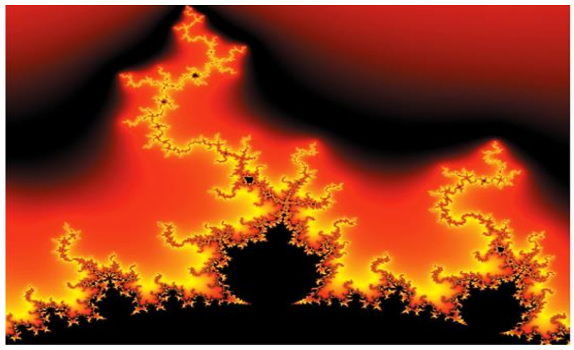

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