ISSN 2444-4995

Journal of Technological Prototypes

Volume 8, Issue 22 — July — December — 2022

ECORFAN®

Journal of Technological Prototypes, Volume 8, Issue 22, July – December 2019, is a journal edited sixmonthly by ECORFAN-Spain. 38 Matacerquillas street, Postcode: 28411. Moralzarzal – Madrid WEB: www.ecorfan.org/spain, journal@ecorfan.org. Editor in Chief: QUINTANILLA - CÓNDOR, Cerapio. PhD, ISSN On line: 2444-4995. Responsible for the latest update of this number ECORFAN Computer Unit. ESCAMILLA-BOUCHÁN, Imelda. PhD, LUNA-SOTO, Vladimir. PhD, 38 Matacerquillas street, Postcode: 28411. Moralzarzal – Madrid, last updated December 31, 2022.

Journal of Technological Prototypes

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Presentation of Content

In the first article we present, *Medical gas monitoring design applying image processing* by CÓRDOVA-MANZO, Jesús Fausto, CÓRDOVA-ESCOBEDO, Jesús Fausto, MENDOZA-GONZÁLEZ, Felipe and LÓPEZ-LIÉVANO, Adolfo, with adscription in the Universidad Veracruzana, as next article we present, *Development of a Peristaltic Pumping System for the Micro Fuel Cells Evaluation (µFC)* by HERÁNDEZ-FIGUEROA, Rodolfo, GURROLA, Mayra Polett and CRUZ-ARGÜELLO, Julio César, with adscription in the Instituto Tecnológico de Chetumal and CONACYT, as next article we present, *Proposal for the design and manufacture of a dynamic orthoses prototype for hand rehabilitation* by MONTIJO-VALENZUELA, Eliel Eduardo, with adscription in the Universidad Estatal de Sonora, as next article we present, *Mechanical characterization of tin coatings with biomedical application in elbow prostheses* by CABRERA-ROSAS, Yazmin, MELO-MÁXIMO, Lizbeth, MELO-MÁXIMO, Dulce Viridiana and ÁVILA-DAVIAL, Erika Osiris, with adscription in the Tecnológico Nacional de México, Instituto Tecnológico de Tlalnepantla, Instituto Tecnológico de Estudios Superiores de Monterrey-Campus Estado de México and the Tecnológico Nacional de México, Instituto Tecnológico de Pachuca.

Content

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Medical gas monitoring design applying image processing

Diseño de monitoreo de gases médicos aplicando procesamiento de imagen

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DOI: 10.35429/JTP.2021.22.8.1.10 Received July 12, 2022; Accepted October 15, 2022

Abstract

Design of a methodology, that uses image processing to monitor the pressure indicators of medical gas tanks (oxygen and nitrogen) used in hospitals to care for patients who require it. This system can notify the pressure level reported by the indicators and its contribution is the application of technology that prevents the displacement of medical or technical personnel to the gas installations, resulting in a remote monitoring system.

Monitoring, Processing, Application

Resumen

Diseño de una metodología, que emplea procesamiento de imagen, para el monitoreo de los indicadores de presión de los tanques de gases medicinales (dióxido de carbono y nitrógeno) que se usan en los hospitales para atención a pacientes que lo requieren. Este sistema es capaz de notificar el nivel de presión que reportan los indicadores y su contribución es la aplicación de la tecnología evitando el desplazamiento del personal médico o técnico a las instalaciones de gases, resultando en un sistema de monitoreo remoto.

Monitoreo, Procesamiento, Aplicación

Citation: CÓRDOVA-MANZO, Jesús Fausto, CÓRDOVA-ESCOBEDO, Jesús Fausto, MENDOZA-GONZÁLEZ, Felipe and LÓPEZ-LIÉVANO, Adolfo. Medical gas monitoring design applying image processing. Journal of Technological Prototypes. 2022. 8-22: 1-10

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Introduction

The medical gases network is a fundamental facility for any health institution, they are part of ventilation systems (where critical ill patients are cared for) and (Girón, 2012).

The applications vary according to the gas being handled, for instance: oxygen is used for oxygen therapy, respiratory therapy, and hyperbaric chambers, among others. For its part, nitrogen is used to mobilize pneumatic equipment, preservation of blood and organs (Isaacs, 1992).

The medical gas system participates in different units and departments of the hospital such as the intensive care unit, emergencies, operating rooms, among others. To ensure the correct supply and distribution of gases, certain basic elements must be considered in the installation of medical gases.

Basic elements of the medical gases system. (SeisaMed, 2019)

Medical gases hoses

They are elements designed for the centralized distribution of gases to the departments and units that require the supply. Those hoses that handle high pressure have a stainless-steel jacket. Hose colors comply with NFPA-99 code.

Figure 1 Hoses for medical gases
Source: JGE Equipos Médicos y Hospitalarios

Gas network installation

It is the supply system to provide medical gases to various areas of the hospital continuously.

Medical gases connections

They are couplings that vary according to their use: vacuum regulators, flow meters, high pressure hoses and other equipment.

Shear box

The shear boxes have manometers to measure the gas pressure, an aluminum window and transparent polycarbonate

Figure 2 Shear box for medical gases
Source: JGE Equipos Médicos y Hospitalarios

Depending on where they're placed, they allow the flow of different clinic areas to be separated.

Gas regulators

Elements in charge of measuring and controlling the pressure levels of medical gases through the rest of the central network.

Wall suction unit

Given the high pressure with which the gases are distributed, an element is necessary that connects to the gas inlet consoles and allows a safe, controlled, and regulated aspiration.

Figure 3 Wall unit with regulator
Source: JGE Equipos Médicos y Hospitalarios

ISSN 2444-4995

Manifold

System that allows an uninterrupted supply of a certain gas at constant pressure. We could list these four components of a manifold (Isaacs, 1992):

– Bench. Where several cylinders that operate at the same time are integrated.
– Header. Pipe that connects to the bench.
– Valve. Connects the header to a distribution pipe.
– Control. Interaction between meters and regulators of pressure and flow in the distribution network.

Figure 4 All the automatic manifold elements
Source: Own Elaboration

There are manual, semi-automatic and automatic collectors. However, regardless of the type of collector, personal supervision is required to verify its operation.

Automatic Manifold
(SeisaMed, 2020)

An automatic collector, in a hospital, has the function of controlling the flow and pressure of the medical gases that are stored in the high-pressure cylinders (bank in operation and reserve bank). This type of collector allows the gas supply in hospital gas networks to be continuous. The advantage of an automatic manifold is that it can be switched to the reserve bank when the pressure of a certain gas at the source (supply bank) is reduced, carrying out a series of automatic transfers to be able to go from the reserve option to that of option of use.

Always maintaining the pressures and flows within the desired value without automatically suffering any disturbance or fluctuation, and without the intervention of the personnel in charge of this area of operation.

The manifold has led indicators and displays, which show the necessary information to be able to know the pressure levels, the bank in use, availability of the reserve bank, alarm messages, gas consumption and event log. This control panel is easy to use, and the indicators can be analog or digital.

For example, the automatic oxygen collector shown in figure 5, has 6 LEDs and 3 screens, where the upper screen shows the supply to the oxygen network and the other two screens show the capacity of the banks. The LEDs show which bank is in use (left or right) and whether the bank has spare capacity or is empty.

The green LEDs at the top inform which bank is in use, turning on the light on that side, while the reserve light remains off. Below them are the yellow LEDs, which indicate which is the reserve bank. Logically, the green and yellow indicators on the same side of the board will never be on. Finally, we have the red led, which indicates that the bank is empty. The light from the LED spotlights is of such intensity that it can be seen even in low light conditions. The manifold also has pressure regulators for each of the banks to control the line pressure required by the supply networks.

It has a safety device that is a relief valve for the intermediate line that is connected to a ventilation outlet, in case of overpressure.

Even though the operation mentioned above does not require the intervention of the personnel responsible for this area. If it is essential that the staff be aware that the reserve bank is always available or full. Because if the banks in use and reserve are empty at the same time, the collector will not be able to supply medical gases to the hospital gas network, causing unwanted situations in patient care.

Figure 5 Schematic of an automatic manifold
Source: Operation and maintenance manual. Automatic Medical Gas Manifold. NFPA v1.5 regulator incorporated in Digital Dome. Amico

Figure 6 Frontal panel with led indicators
Source: Operation and maintenance manual. Automatic Medical Gas Manifold. NFPA v1.5 regulator incorporated in Digital Dome. Amico

Metodology

Phase 1. Database of photographs of the indicator panel of the automatic manifold

It is desirable that the photographs be captured at the same distance, as if the camera were fixed. This is done to obtain uniform samples and avoid making subsequent adjustments to the images (Mora, 2021). The image shown in Figure 7 was taken as a pattern, where all the indicators can be seen with a considerable distance from the lens to the front panel.

Figure 7 Outline of front panel indicators
Source: Operation and maintenance manual. Automatic Medical Gas Manifold. NFPA v1.5 regulator incorporated in Digital Dome. Amico

The set of photographs that was captured consists of:

- 10 photos have the 'Reserve' indicator lit on the left and the 'In use' indicator on the right.
- 10 photos have the 'Reserve' indicator lit on the right and the 'In use' indicator on the left.
- 10 photos have the 'Empty' indicator lit on the left.
- 10 photos have the 'Empty' indicator lit on the right.

40 images were captured for each manifold, therefore, since we are working with carbon dioxide and nitrogen, the database is made up of 80 photographs.

Figure 8 Front panel of automatic nitrogen manifold indicating that the right bank is in use and the left is in reserve
Source: Own Elaboration

ISSN 2444-4995

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Figure 9 Automatic carbon dioxide manifold front panel indicating that the right bank is in use and the left bank is in reserve
Source: Own Elaboration

Figure 10 Front panel of the automatic nitrogen manifold indicating that the left bank is in use and the right bank is in reserve
Source: Own Elaboration

Figure 11 Front panel of automatic carbon dioxide manifold indicating that the left bank is in use and the right bank is in reserve
Source: Own Elaboration

Figure 12 Front panel of automatic nitrogen manifold indicating that the left bank is empty, and the right bank is in use
Source: Own Elaboration

Figure 13 Front panel of automatic carbon dioxide manifold indicating that the left bank is empty, and the right bank is in use.
Source: Own Elaboration

Figure 14 Front panel of the automatic nitrogen manifold indicating that the right bank is empty and the left one is in use
Source: Own Elaboration

Figure 15 Front panel of automatic nitrogen dioxide manifold indicating that the right bank is empty, and the left bank is in use
Source: Own Elaboration

Phase 2. Image processing for detection of LEDs indicators

As all the photos of a gas manifold have the same dimensions and we intend to visualize the LEDs indicating the state of the tank, a cut is made in the LEDs.

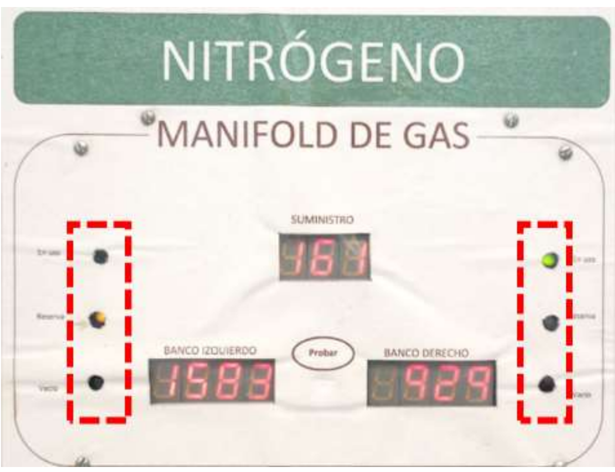

Figure 16 Areas of interest of the automatic manifold
Source: Own Elaboration

Before cutting out the area of the LEDs from the image to focus on what state the tank is in, a reading of the images is performed. The following program in MatLab allows the analysis of the data from the photographic database

```
clc
% Nitrogeno
i1=imread('Diapositiva1.JPG')
i3=imread('Diapositiva3.JPG')
i5=imread('Diapositiva5.JPG')
i7=imread('Diapositiva7.JPG')
subplot(2,2,1); imshow(i1);
subplot(2,2,2); imshow(i3);
subplot(2,2,3); imshow(i5);
subplot(2,2,4); imshow(i7);
```

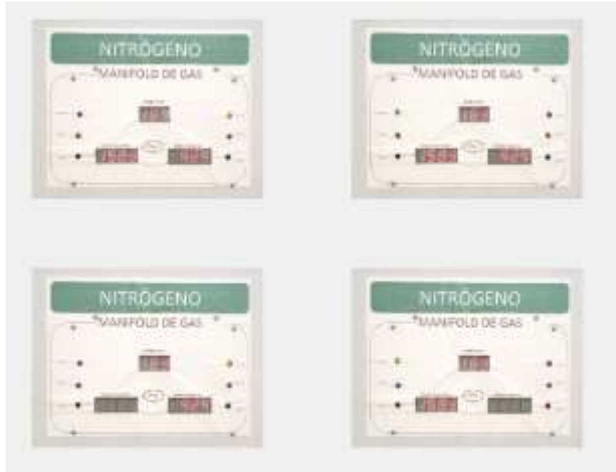

Figure 17 Figure generated in MatLab where the 4 possibilities of the nitrogen manifold are shown
Source: Own Elaboration

The most convenient area to display the LEDs on the left and right side is selected. Next, the code used to clip the LEDs on the left side.

```
figure()
ledsIzqi1=i1(231:375,104:135,:);
subplot(4,2,1); imshow(ledsIzqi1);

ledsIzqi3=i3(231:375,104:135,:);
subplot(4,2,3); imshow(ledsIzqi3);

ledsIzqi5=i5(231:375,104:135,:);
subplot(4,2,5); imshow(ledsIzqi5);

ledsIzqi7=i7(231:375,104:135,:);
subplot(4,2,7); imshow(ledsIzqi7);
```

The program generated the following graph

Figure 19 Graph generated in MatLab where the LEDs on the left side are shown
Source: Own Elaboration

In a similar way, we proceed to choose an area that covers the LEDs on the right side, this region is repeated with the program for all the images since they have the same dimension.

```
ledsDeri1=i1(236:371,498:529,:);
subplot(4,2,2); imshow(ledsDeri1);
ledsDeri3=i3(236:371,498:529,:);
subplot(4,2,4); imshow(ledsDeri3);
```

```
ledsDeri5=i5(236:371,498:529,:);
subplot(4,2,6); imshow(ledsDeri5);

ledsDeri7=i7(236:371,498:529,:);
subplot(4,2,8); imshow(ledsDeri7);
```

Figura 19 Graph generated in MatLab where the leds on the left and right sides are shown
Source: Own Elaboration

Phase 3. Image processing to detect the color of LEDs indicators

It is important to remember that the color space used is RGB, therefore, if we consult for each channel of the matrix, we will observe a gray scale, which represents the contribution of the brightness of each pixel in that channel (Alegre, 2003). For example, if we have a red dot on a black background in an image and ask for the R channel of that image, we will get a white dot on a black background.

Taking this into account, it is about looking at the contribution of each pixel in the most convenient channel (R, G or B) and performing the binarization process to further emphasize said contribution (González, 1996).

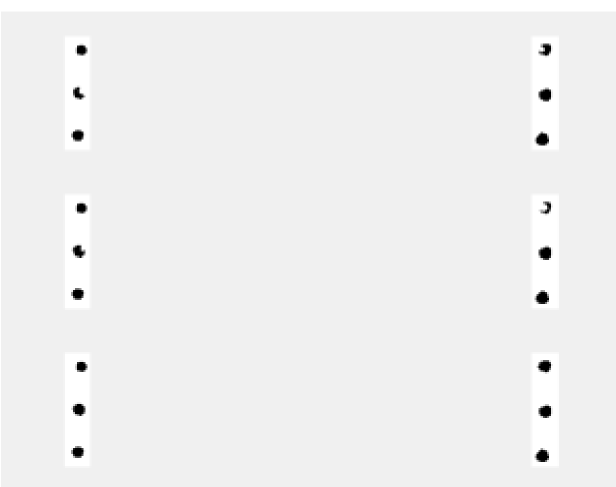

Figure 20 Figure generated in MatLab where the R, G and B channels of the 3 left and right LEDs are shown
Source: Own Elaboration

As can be seen, Figure 20 is the result of asking for the pixel contribution in the R, G and B channels. Considering that Figure 8 (attached below) is being processed, it makes sense that the right LED, which is the green LED, shine brightest on the G channel, while the left LED, which is orange, contributes to the R and G channels.

Figure 21 Correspondence of the colors of the LEDs with their brightness in the different channels
Source: Own Elaboration

We proceed to add the images, obtaining:

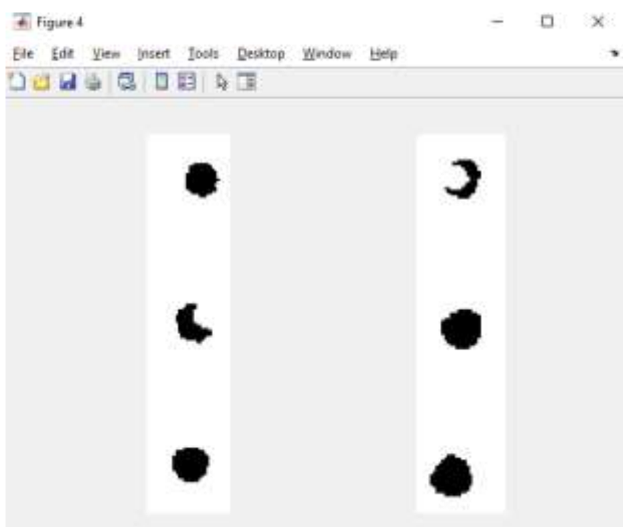

Figure 22 Contributions from each pixel in the R, G and B channel added together
Source: Own Elaboration

After having added the contribution of the pixels in each channel, it is easy to conclude that those LEDs on will provide more brightness to the R, G or B channels and when binarizing the pixels with the greatest contribution turn white, so that the circles with less area are those where the led is on.

It is proposed to divide the resulting image into 3 sections, corresponding to the indicator LEDs on each side.

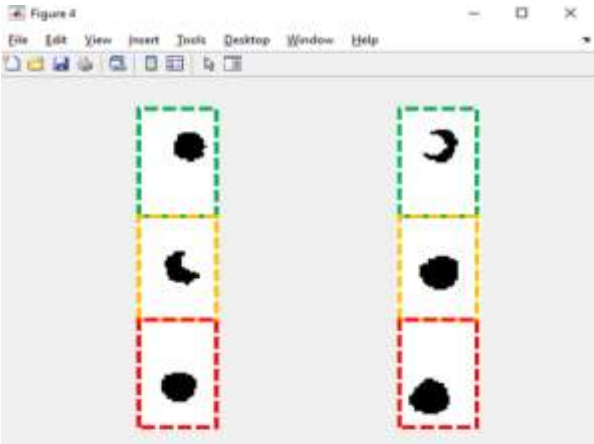

Figure 23 Contributions from each pixel in the R, G and B channel added together
Source: Own Elaboration

Subsequently, the resulting image is divided into 3 sections, corresponding to the indicator LEDs on each side, to determine which is the circle with the smallest area, compare them between them and determine which led is on.

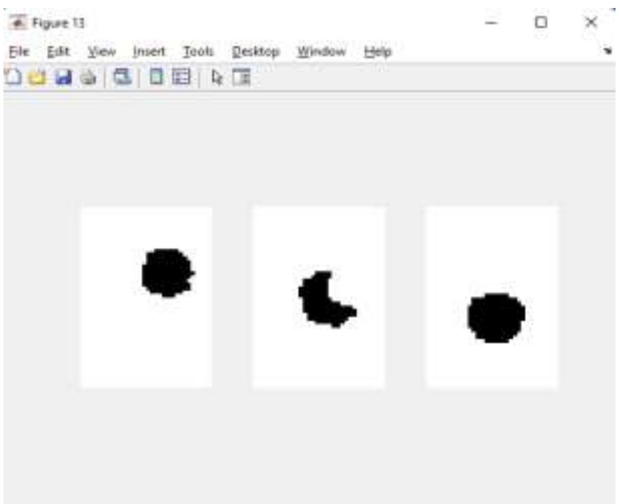

Figure 24 MatLab figure showing the LEDs on the left side. In this case, the orange led (in the middle) is the power led
Source: Own Elaboration

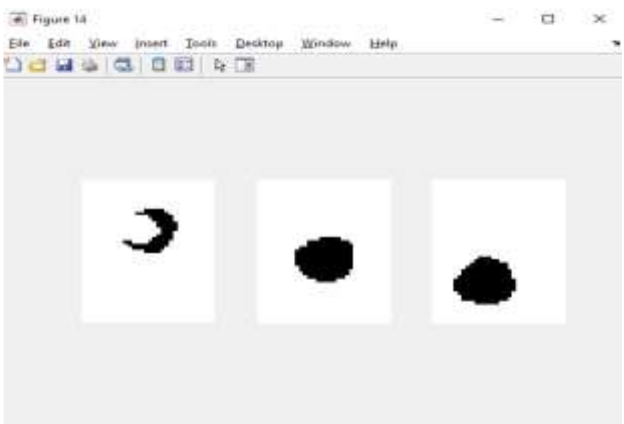

Figure 25 MatLab figure showing the LEDs on the right side. In this case, the green led (left) is on
Source: Own Elaboration

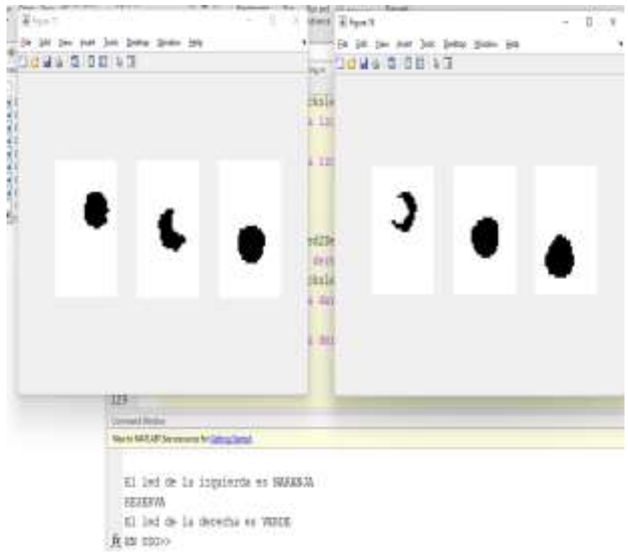

Figure 26 MatLab command window where the result is displayed after comparing the number of black pixels in all sections
Source: Own Elaboration

Applying the previous methodology, we can process the images in the same way since they have the same dimensions and thus determine which led is the lighting.

Phase 4. Notification

In the case of detecting any of the red LEDs lit, the system will be able to warn of the detected event by means of an audible alarm, which will be played on the PC.

This will allow technical or medical personnel to be informed in real time that the medical gases in the high-pressure cylinders of the reserve bank are empty.

This will make it possible to take immediate actions such as recharging gas or replacing empty reserve banks with full ones, so that the reserve system is always available and avoids problems in patient care. This notification allows remote monitoring of the manifold, optimizing the travel times of the personnel to know how the readings are.

Results

The results are in line with expectations. The implementation of the proposed methodology allows to easily detect the lit LEDs and thus know the status of the tanks, if they are in use, if they are in reserve or if they are empty. Below we can see a table with the images of the LEDs that light up and the estimate of the appropriate LEDs that light up from the image processing.

Nitrogen Manifold

Real / Obtained	R.: Use L.: Reserve	R.: Reserve L.: Use	R.: Empty L.: Use	R.: Use L.: Empty
R.: Use L.: Reserve	10	0	0	0
R.: Reserve L.: Use	0	10	0	0
R.: Empty L.: Use	0	0	10	0
R.: Use L.: Empty	0	0	0	10

Tabla 1 Results of the processing of the images of the automatic nitrogen manifold

The reported high efficiency is due to the uniformity of the image dimensions and the lighting conditions of the front panel. As can be seen in the previous table, there are no false positives, all the results the system yields coincide with what is expected thanks to image processing, which allows us to quickly identify the contribution in the different channels (R, G or B) of the image and so binarize them to glimpse which are the lit LEDs.

Carbon Dioxide Manifold

Real / Obtained	R.: Use L.: Reserve	R.: Reserve L.: Use	R.: Empty L.: Use	R.: Use L.: Empty
R.: Use L.: Reserve	10	0	0	0
R.: Reserve L.: Use	0	10	0	0
R.: Empty L.: Use	0	0	10	0
R.: Use L.: Empty	0	0	0	10

Table 2 Results of the processing of the images of the automatic carbon dioxide manifold

Similarly, there were no erroneous detections for the carbon dioxide manifold, this methodology covering all cases and correctly identifying them.

Conclusions

As future work, the lighting of the environment should be taken into consideration since at the time of binarizing, it is possible that the background is not white and may turn black if the images are captured at night.

An improvement that could be implemented consists of segmenting the LEDs to check their color and ignoring external factors such as lighting depending on whether it is day or nighttime.

It is possible to add another kind of alarm apart from playing audio on the PC. One of the most practical and feasible possibilities is to send an email to the department in charge of supplying medical gases (usually Maintenance) notifying them that one of the manifold’s intake tanks is empty.

The implementation of this proposal solves the cumbersome task of constantly going to check the status of the tanks, saving time, personnel, and resources in hospitals.

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Journal of Technological Prototypes
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Development of a Peristaltic Pumping System for the Micro Fuel Cells Evaluation (μFC)

Desarrollo de un Sistema de Bombeo Peristáltico para Evaluación de Microceldas de Combustible (μCC)

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DOI: 10.35429/JTP.2022.22.8.11.18 Received August 30, 2022; Accepted October 20, 2022

Abstract

Urea $(CO(NH_2)_2$ waste substance, which some living beings expel through urine and sweat, being produced as a final result of protein metabolism and as a means of eliminating ammonia, is contained in wastewater and is considered a promising source of renewable energy with the potential to be exploited through electrochemical processes such as those used in microfluidic fuel cell (μFC) technology, however, the progress of these technologies is hampered due to the high cost of devices for evaluating their performance, a clear example is syringe infusion pumps, in addition to their impractical manual operation for constant power generation. In the present work, the development of a low-cost microfluidic delivery device is shown, capable of replacing syringe infusion pumps in terms of precision, in addition to having a completely autonomous operation, profiling it for a possible incorporation in a waste-based energy generation system such as urea, having the ability to contribute to the development of renewable energies without the need for excessive capital investment.

Microfuel cell, Urea, Energy Conversion, electrochemical

Resumen

La urea $(CO(NH_2)_2$ sustancia de desecho, que algunos seres vivos expulsa a través de la orina y el sudor, siendo producida como resultado final del metabolismo de las proteínas y como medio de eliminación del amoníaco está contenida en aguas residuales y se considera una fuente prometedora de energía renovable y con un potencial de aprovechamiento a través de procesos electroquímicos tales como los empleados en la tecnología de las celdas de combustible de microfluidicas (μFC). Sin embargo, el avance de esas tecnologías se ve mermado debido al alto costo de dispositivos para la evaluación del rendimiento de las mismas, un claro ejemplo son las bombas de infusión de jeringa, además de su operación manual impráctica para la generación de energía constante. En el presente trabajo, se muestra el desarrollo de un dispositivo de impulsión microfluídica de bajo costo, capas de sustituir a las bombas de infusión de jeringa en cuanto a su precisión, además de contar con una operación completamente autónoma, perfilándolo para una posible incorporación en un sistema de generación de energía a base de desechos como la urea, teniendo la capacidad de contribuir al desarrollo de energías renovables sin necesidad de una excesiva inversión de capital.

Microcelda de combustible, Urea, Conversión de Energía, Electroquimica

Citation: HERÁNDEZ-FIGUEROA, Rodolfo, GURROLA, Mayra Polett and CRUZ-ARGÜELLO, Julio César. Development of a Peristaltic Pumping System for the Micro Fuel Cells Evaluation (μFC). Journal of Technological Prototypes. 2022. 8-22: 11-18

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Introduction

Peristaltic pumps present an alternative to syringe infusion pumps, without compromising the wide variety of applications to which they can be deployed, one of them being fuel testing for microfluidic fuel cells (μCC)[1][2], thanks to the reduced manufacturing price and the wide variety of open licensing material for their designs, they are emerging as a lowering the barrier to entry for microfluidic technology [3][4].

Among other applications in the medical industry, they are used in a wide range of disciplines and techniques, such as cell biology, tissue engineering, drug monitoring, single-cell analysis and manipulation under multiple conditions, molecular biomotors, among others [5][6]. In the engineering field, for roller pumps, transport of sanitary fluids, and for the transport of corrosive liquids, where it is necessary that no physical element of the pump interacts with the reagent, transit of toxic liquids for the nuclear industry, in the transport of nanofluids for better thermal conductivity with asymmetric channels, and many others [7][8].

All the drawbacks generated by current technologies in microfluidic systems corresponding to pumping, slows down the progress of all other technologies that depend on it, so it is necessary more pumps independent of human action to increase the testing times of these devices, as well as reduce the supervision of researchers, and that do not present an economic barrier for any laboratory that needs to do tests of this nature [9][10].

In this sense, this work develops a manufacturing process for a peristaltic pump as an alternative to syringe infusion pumps in the dosing of fuel in microcells, which is low cost, non-polluting, totally autonomous from human supervision over long periods of time, and modular for the addition of future functionalities. Therefore, the design and manufacture of the prototype, as well as the functions of the electrical elements that make up the motor, which are: the movement of the motor.

Experimental Section

Peristaltic pump design

For the prototype a red thermoplastic filament was used as 3D printing material, due to its low cost and easy modification of physical parameters, as well as the use of AutoCAD software for the modelling of the parts.

The cover was a square of 42.33 mm per side with circular curved edges at the centre of the screw holes. The base is identical to the cover, but additionally, it had an inner semi-circle 28 mm in diameter and 8 mm deep; the middle of the circle follows a straight channel to reach the pipe outlet.

The upper and lower holder, cylindrical figure of 28 mm diameter, with different depth, upper 4 mm, while lower 3 mm deep.

Selection and connection of electronic components

Motor: a NEMA 17 stepper motor was used as the main modulation component.

Controllers: an Arduino Nano board as the controller for the motor and a DRV8825 Driver, which allowed micro stepping up to 1/32 per step, for a smoother motion, and as a result, less vibration to the physical parts of the pump.

Power supply: a DC power supply of E=12 V at I=2 A, connected in parallel with a 200 μF capacitor, in order to avoid overcurrent to the driver. The power supply for the Arduino NANO board was taken at 5 V directly from the USB port of a computer.

Potentiometer: A 10 KΩ resistance potentiometer was used to include a variable analogue value to generate a variable digital signal to create a real time flow measurement value that was projected on the LCD display.

LCD Display: A 20 x 4 digit LCD display, which was used for user control of the pump, which allowed the real time flow values to be displayed in μL/min.

I2C module: A common I2C module that reduced the number of connections of the LCD display from 16 to 4, which generated less source code.

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Journal of Technological Prototypes
December 2022 Vol.8 No.22 11-18

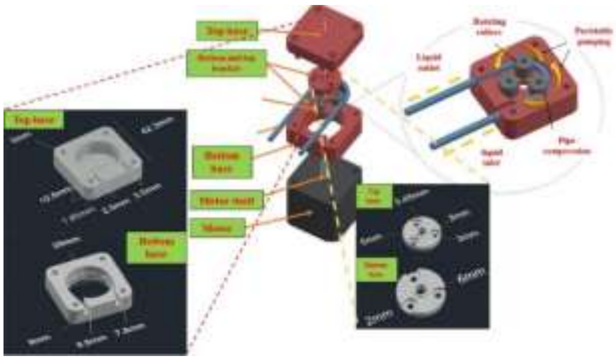

Figure 1 Schematic of peristaltic pump design

Wiring diagram

Figure 2 shows the connection diagram between the terminals of the microcontroller board, the driver and the motor:

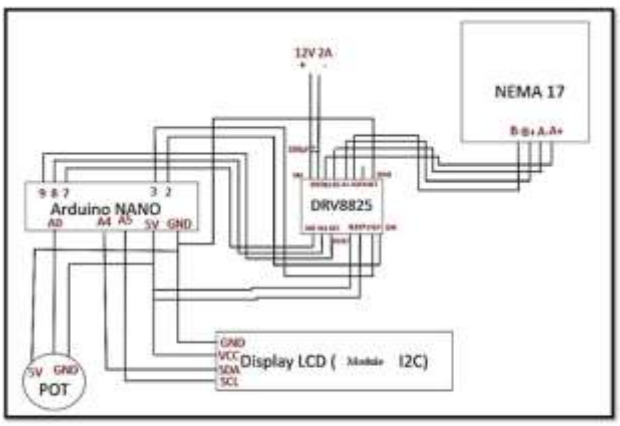

Figure 2 Peristaltic Pump Internal Wiring Diagram

High voltage terminals

From the motor coils A+, A-, B+, B-, they were connected to terminals B2, B1, A1, and A2, of the Driver respectively. A 12V 2A power supply was connected in parallel to this motor, with a capacitor of at least 100µF. Finally, the ground of the DRV8825 was connected to the built-in ground of the Arduino NANO.

Low voltage terminals

The address and pass-through pins were connected to terminals 2 and 1 of the Arduino NANO, as well as the logic outputs M0, M1, and M2, to pins 7, 8, 7 9, respectively. Both the Sleep and Reset ports were connected to the on-board 5 V output. For the potentiometer we took two power terminals, 5 V and GND, and one terminal to send the variable resistance value, which was A0 from the Arduino board.

Connection of the LCD display and the I2C module

An I2C module was used, which reduced the number of connections from 16 on the LCD to only 4 on the I2C module, two of them being 5V power and ground (which was taken from the 5V and GND output of the Arduino board), and the SDA and SCL inputs.

Internal assembly

Due to the prototypical design of the container, the components were kept on the connection board to avoid any possible connection limitations in anticipation of adding future functionality to the pump, the only notable adjustments were the extension of the Arduino board with wires to be placed in the connection output port (next to the motor power supply) and the soldering of the switch to avoid false contacts in the fundamental operation of the power supply.

External mounting

For the prototypical design, a plastic container was used as a container for the electronic components and the pump, in which 6 external elements for user control are located as shown in Figure 3:

Display

The LCD screen that visualises the flow in real time; Flow control: A knob added to the potentiometer to increase or decrease the flow; Shutdown: An on/off switch for the pump operation; Power port: An input cable connection for power, a micro USB port for the Arduino Nano board and another cable for the main motor power; Suction and pumping pipes: The silicone pipes coming out of the motor to be placed in any container that the user wishes.

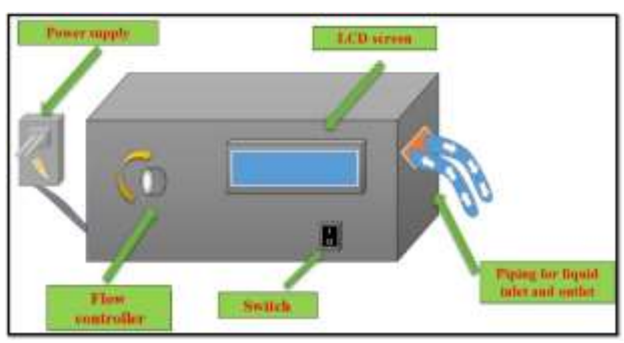

Figure 3 Components of the external prototype pump

Source code

Motor movement

The following code was created using the Arduino software for programming boards of this type. The following lines were used to define the direction and step pins used on the board, as well as the declaration of the constant "StepsPerRevolution" with the number of steps of the motor, which in the case of the NEMA 17, was 200 steps.:

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27,20,4);
#define dirPin 2
#define stepPin 3
#define stepsPerRevolution 200
void setup() {
  lcd.init();
  lcd.backlight();
  lcd.clear();
 lcd.setCursor(0,0);
  lcd.print("FLUX CONTROL");
  lcd.setCursor (0,1);
  lcd.print("PUMP ");
  pinMode(stepPin, OUTPUT);
  pinMode(dirPin, OUTPUT);
}
void loop() {
  int sensorReading = analogRead(A0);
  int motorSpeed = map(sensorReading, 0, 1023, 0, 1000);
  digitalWrite(dirPin, LOW);
  for (int i = 0; i < 1; i++) {
    digitalWrite(stepPin, HIGH);
    delay(motorSpeed);
    digitalWrite(stepPin, LOW);
    delay(motorSpeed);

     lcd.display();


  float FLUX = sensorReading * (1000.0 / 1023.0);
  lcd.setCursor (0,1); //
  lcd.print("Flux:");
  lcd.setCursor (8,1); //
  lcd.print(30000*(2.5717/FLUX)); // print
  lcd.setCursor (12,1); //
  lcd.print("uL/m");
  }

  }
```

Source code

Motor movement: The following code was created using the Arduino software for programming boards of this type. The following lines were used to define the direction and step pins used on the board, as well as the declaration of the constant "StepsPerRevolution" with the number of steps of the motor, which in the case of the NEMA 17, was 200 steps:

$$Drive\ distance = \frac{\pi * Diameter}{4} = \frac{\pi(28\ mm)}{4} = 7\pi\ mm \quad (1)$$

The cross-sectional area of the pipe was calculated, taking into account a diameter of 3.75 mm

$$A = \pi\left(\frac{3.75\ mm}{2}\right)^2 = 11.0447\ mm^2 \quad (2)$$

The value obtained was multiplied by the delivery distance to obtain the delivered volume in cubic millimetres.

$$V = A * Drive\ distance = (11.0447\ mm^2)(7\ \pi mm) = 242.8848\ mm^3 \quad (3)$$

Finally, the value was divided by the number of 90° steps to obtain the impulse volume in cubic millimetres.

$$V_{Per\ step} = \frac{242.8848\ mm^3}{50\ steps} = 4.8577\ mm^3/step \quad (4)$$

After appropriate conversions, the above value was exactly the same as the amount in microlitres, so the minimum impulse volume per step was 4.8577 µL/step.

Estimation of actual flow per step

As it is impossible to determine exactly where in the cycle the pump is at any given time, an approximation was made for any given value by establishing a relationship between the total number of steps in the cycle and the delivery steps, as follows:

Percentage of impulsion per step=36/68=9/17%=52.9412 % (6)

A theoretical flow in the step unit was estimated by multiplying the volume per step by the percentage of impulse per step:

$$V\ per\ estimated\ step = (4.8577\ \mu L)\frac{9}{17}\% = 2.5717\ \mu L \quad (7)$$

This estimate allowed us to establish the amount of flow per minute, and for fuel cell applications, where several hours of pump operation is required, this estimate does not present any problems in terms of accuracy.

Conversion of potentiometer reading to display flow rate value

To set a reading from 0 to 1000 in the physical potentiometer resistance values, the same value was used in the one step engine movement instruction in the "delay" instruction, one "delay" to give the move instruction.

And another to give the stop instruction, therefore, the time it took the motor to move one step is twice the amount of delay sent by the potentiometer at a specific moment, taking into account that the "delay" instruction takes values in milliseconds, it was possible to determine a function for the time it took the motor to move one step according to the values read by the potentiometer, being determined as [14]:

$$T_{step/s} = \frac{2Delay}{1000} \quad (8)$$

Where: $\boldsymbol{T_{pasos/s}}$: The time it took for the engine to take one step, in seconds. Delay: The Delay value read by the Arduino board as a result of changing the resistance on the potentiometer, from 0 to 1000. Therefore, in T Step/s, the amount of volume per step determined in the previous subchapter must be shifted, the number of steps in minutes was found by a simple rule of three, the expression for steps per minute was expressed as follows:

$$Steps_{/min} = \frac{60}{\frac{2Delay}{1000}} = 30000/Delay \quad (9)$$

Once the value of the volume per step and the number of steps per minute were obtained, the volume per minute in µL/min was obtained by multiplying them, the final value of the flow rate was set as:

$$Flow = 30000\frac{V_{Per\ step}}{Delay} \quad (10)$$

This value is the function that was introduced in the code with the "print" instruction that allowed to visualise the flow on the Display.

Results

Thermoplastic filament prints and pump construction

After testing various models, the thermoplastic filament parts were obtained with the help of a 3D printing service, with the necessary dimensions for the correct functioning of the pump.

Figure 4 a) b) 3D printing of parts for pipe encapsulation and b) Assembly process of the pipe encapsulation

As shown in Figure 4, the encapsulation for the proposed base pipe was constructed, which allowed installation in 4 steps, as shown in Figure 6.2, which were, in the first instance, construction of the "roller" piece with the two support pieces containing 6 bearings (2 for each hole in vertical position) all secured with 3 M3 screws. Then the base was placed on the motor and the roller part on the shaft. As a third step, the pipe was placed around the roller piece, holding the pipe, while the roller piece was pushed down to encapsulate the pipe inside the base, it was necessary to make some small adjustments in the pipe, as it did not enter uniformly along the circumference of the base, which we can parrot by turning the roller piece and introducing it more thoroughly. Finally, the cover was fitted, making sure to pull the two outlets of the tubing and then screw the tubing into the 4 holes so that the tubing was confined in the casing.

Pump control

The precise and controlled movement of the motor was achieved with a combination of code loaded on the Arduino Nano board, and the DRV8825 Driver for communication with the motor [15][16]. Additionally, the internal code of the Arduino board was adjusted to work based on the variable resistance reading of a 10KΩ potentiometer, and this reading is converted into actual flow values within the Arduino boards, and subsequently displayed on a 20-column, 4-row LCD screen[17]. To facilitate the connection between the LCD display and the Arduino board, an I2C module was used to reduce the number of connections from 16 to 4. Finally, the motor was powered with a 12V 2A DC power supply, with a 100µF capacitor between the supply terminals and the driver, to protect it from any overcurrent.

Figure 5 Electronic components

Installation of internal components

The internal components were arranged as shown in figure 6.4. These were placed in a plastic container with holes to accommodate all electronic components that would be exposed to a user.

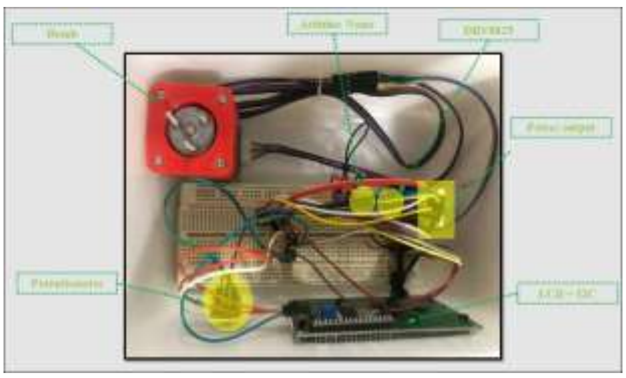

Figure 6 Internal ordering of components

User interface

The 5 elements of which the user has control over the pump are: The LCD display with which the selected flow rate is displayed, a knob to select the flow rate, a button to switch the pump on and off, the output for the power supply, and the output with the suction and delivery pipes.

Figure 7 Mounting of external components on the container

Flow tests

The tests carried out were based on the consideration of 3 phases that are repeated continuously, i.e. a flux cycle, by counting the number of steps in these phases and constant operation in 1h of operation, it was observed that the cycle is repeated every 68 engine steps, 20 for the backward movement, 12 for the recovery, and 36 for the impulsion[18].

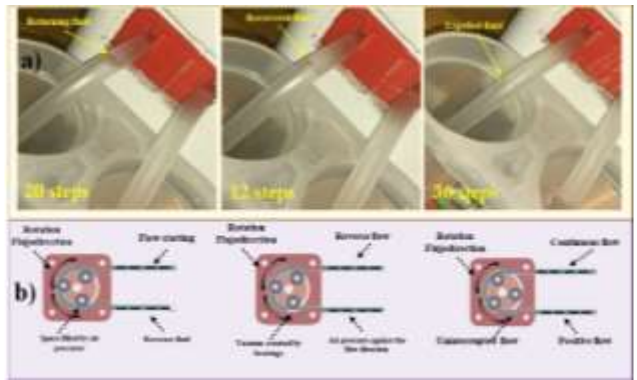

Figure 7 a) Flow continuity tests and (b) Pump cycling

The flow function in µL/min at the rate of change of the Delay was obtained. Given the estimated V per step = 2.5717 µL, it was substituted into equation (10) and a function of the form:

$$Flow = \frac{77151}{Delay}\,\mu L/min \quad (11)$$

This indicated hyperbolic behaviour in the control of the potentiometer, due to the nature of the code used, was checked with a graphical calculator, and the following graph was obtained:

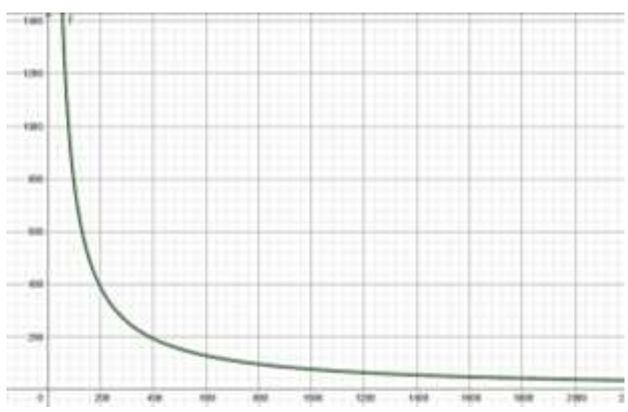

Figure 8 Flow graph as a function of potentiometer Delay

Pump efficiency

The developed prototype achieved a regression cycle of 32 steps and an impulsion of 36 steps, so that, with the calibration in the internal code, a minimum flow rate of 2.5717 µL/min was achieved, in the same range, the knob could increase the flow rate to 200 µL/min. For a wider range of applications, the pump can be ranged and adjusted down to millilitre quantities, whereby a controllable operating range of 1-200 ml/min was obtained with the knob.

Figure 8 Final prototype

This makes it fully compatible for fuel cell reagent feeding needs, as shown in table 1.1. As added functionality, the pump requires no change of suction tubing and the outlets can be placed in any container without the need for supervision of the operation. If required, the stop button allows the user to stop the flow of fluid at any time and will remain static until the pump is started again, with no risk of the suctioned fluid backing up or advancing undesirably.

Acknowledgement

The authors thank the Consejo Mexicano de Ciencia y Tecnología (CONACYT) for their financial support through the Cátedras-CONACYT-Proyecto Número 746 and the Laboratorio Nacional de Micro y Nanofluídica 2022-321116 for their technical support.

Conclusions

The design was an economical and efficient alternative for the replacement of syringe infusion pumps, being only one-sixth the size of a conventional one. Its completely autonomous operation makes it ideal for operation over long periods of work without the need to change the container of the fluid to be pumped, and presents an option for incorporation in energy generation systems based on Urea in the future.

In relation to the tests of the same, the developed prototype is completely suitable for all the ranges in ml/min and µ/min presented in table 1.1. In turn, the code implemented in the microcontroller allows the change of ranges from 2.5 to 200 µL/min, to orders greater than hundreds of microlitres, having a much greater range of availability than the potentiometer can offer. The major contribution of the work is in the high accuracy of the volume displaced per step, which is completely constant in each drive phase, which was the result of multiple combinations of order of tenths of a millimetre between the tubing spaces and the tubing walls.

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Article

Journal of Technological Prototypes

December 2022 Vol.8 No.22 19-29

Proposal for the design and manufacture of a dynamic orthoses prototype for hand rehabilitation

Propuesta para el diseño y manufactura de prototipo de órtesis dinámica para rehabilitación de mano

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DOI: 10.35429/JTP.2022.22.8.19.29 Received September 15, 2022; Accepted December 10, 2022

Absreact

Objetivos The objective of this research is to propose a prototype design of the dynamic orthosis adaptation system for hand rehabilitation. For this, the following methodology was used: the biomechanical and architectural foundations and the functional patterns of the fingers of the hands were previously analyzed, later the test subject was chosen and the corresponding measurements were taken, to finalize the design and manufacture of the prototype. The dynamic orthosis prototype proposed in this research is controlled by servomotors coupled to rings with rigid links, which transmit movement at a certain speed, from the motor axis to the fingers, simulating the biomechanical movements of flexion and extension. The design of this device is focused on users who do not have movement in the phalanges, and thus prevent their muscles from atrophying. The contribution of this research is the development of an economic device that can partially or totally replace the physiological therapies of a patient with problems in the upper limb (hand).

Orthosis, Rehabilitation, Biomechanical

Resumen

El objetivo de esta investigación es proponer un diseño prototipo del sistema de adaptación de órtesis dinámica de rehabilitación de mano. Para ello se utilizó la siguiente metodología: se analizó previamente los fundamentos biomecánicos, arquitectónicos y los patrones funcionales de los dedos de las manos, posteriormente se eligió al sujeto de prueba y se tomaron las mediciones correspondientes, para finalizar con el diseño y la manufactura del prototipo. El prototipo de órtesis dinámica propuesto en esta investigación, se controla mediante servomotores acoplados a anillos con eslabones rígidos, los que transmiten el movimiento a una velocidad determinada, del eje del motor a los dedos, simulando los movimientos biomecánicos de flexión y extensión. El diseño de este dispositivo, está enfocado a usuarios que no tengan movimiento en las falanges, y así evitar que sus músculos se atrofien. La contribución de esta investigación es el desarrollo de un dispositivo económico que pueda sustituir parcial o totalmente las terapias fisiológicas de un paciente con problemas en miembro superior (mano).

Órtesis, Rehabilitación, Biomecánica

Citation: MONTIJO-VALENZUELA, Eliel Eduardo. Proposal for the design and manufacture of a dynamic orthoses prototype for hand rehabilitation. Journal of Technological Prototypes. 2022. 8-22: 19-29

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Introduction

In the last decades it has been observed that a patient's recovery has better results when he or she has a rehabilitation based on therapies, which are regularly applied by physiotherapists and specialised personnel (Merchant *et al.*, 2017). Therapies with dynamic orthoses have demonstrated positive and immediate effects in the recovery of patients with pathologies or injuries associated with the movement of human body limbs (Lu *et al.*, 2022; Kwan *et al*., 2021; Martins *et al.,* 2019; Kora and Abdelazeim, 2019 and Katsuhira, 2018), however, this is a task that requires considerable financial investments by public health institutions, in addition to requiring trained human capital (Duncan *et al*., 2005).

Because of this problem, rehabilitation treatments, including orthoses, have been developed and refined. Orthoses are devices applied externally on the body or a body segment to improve its function (Vargas, 2017), and can be biomechanical devices or appliances, splints, technical aids and supports, which are used in orthopaedics, physiotherapy and occupational therapy (Gavilán, 2017), as they are a very effective method for the prevention and management of contractures; and are part of the comprehensive rehabilitation system (Chandler, 1983).

The purpose of a dynamic orthosis to increase motion is to provide continuous stretch to a stiff body part in one direction and allows the body part to move in the opposite direction (Middleton, 2019). Dynamic orthoses (orientation of the technological prototype of this research), serve to maintain stability, while providing dynamic corrective forces in a suitable position, functionally assisting the weak extensor muscles of the hand (Ayala *et al,* 2015), these can be fitted with actuators such as servomotors (direct current motors, whose shaft rotation can be controlled), adapted with rigid shafts, springs, elastics or rubber bands to provide direct dynamic assistance to the recovery limbs and often, elastic bands are used to provide stretch or other devices that help to perform the movement (Liu *et al.* , 2022; Sun *et al*., 2022; Sheikh *et al*., 2021; Ashmi *et al*., 2021; Xu *et al.,* 2021; Tsabedze *et al*., 2021 and Zhu *et al*., 2021).

In the literature reviewed, a wide range of orthoses applied to different body limbs is shown, ranging from conceptual designs of exoskeletons to assist lower limb rehabilitation (Zhou *et al*., 2021; Li *et al*., 2021; Wang *et al*., 2021; Peng *et al*., 2020 and Shi *et al*, 2019), mechanical design of an exoskeleton for upper limb rehabilitation (Grosso and Tibaduiza, 2009), and recently, dynamic orthotic designs for upper limb rehabilitation with control systems (Wong *et al*., 2022; Wang and Barry, 2021 and Medina *et al*., 2021) and artificial intelligence (Pattanshett and Khan, 2022; Huang and Wang, 2022 and Velez *et al*., 2021).

Problem statement and rationale

Disability in an individual is understood as any restriction or absence of the ability to perform an activity in the manner or within the range considered normal (Asún, 2017). More than one billion people worldwide suffer from some form of disability, and between 110 and 190 million adults have significant difficulties in functioning (WHO, 2017). In 2014, in Mexico, 3.8 million women and 3.3 million men had a disability, and 33% of this figure had difficulty moving or using their arms or hands (Instituto Nacional de Estadística y Geografía, 2016).

In Mexico, the number of people trained in the fabrication and fitting of prostheses and orthoses is limited. In context, by 1982 the only school dedicated to this speciality in the country closed and currently some institutions in Veracruz and Querétaro are joining efforts to develop the professional career of prosthetists and orthotists, however, the development of this area is still stagnant (Vázquez, 2016).

The World Health Organisation (WHO) states that for every 500 people with disabilities, there should be one professional prosthetist or orthotist (Gómez, 2021). Taking the data established by INEGI and the recommendation established by the WHO, there should be at least 2000 professionals in this speciality area, however, there is only around 15% of the demand.

It is necessary to generate development projects in innovation based on the argument of being able to assist the performance of hand mobility, which, being impaired, impedes the performance of daily life activities.

For this reason, through the development of this orthosis, it will be possible to replace the complete or partial functionality of the flexion and extension movements of the fingers of the hand. Based on the above, the aim is to develop an external aid of the dynamic rehabilitation orthosis type, which seeks to supply or complement the altered biomechanical performance at hand level, thus allowing the flexion and extension movements of the phalanges to be carried out by means of a system integrated into the orthosis based on servomotors, to facilitate the performance of the upper limb.

Research objectives

The general objective of the research is to propose a prototype design of a servomotor-controlled dynamic rehabilitation orthosis adaptation system for upper limb finger flexion and extension movements, to strengthen the hand of people with early stage injuries, through low-cost technologies (integrated control devices, servomechanisms and additive manufacturing).

The specific objectives are:

– Select the test subject for the determination of the geometric and biomechanical parameters of the hand.
– Model the device using Computer Aided Design (CAD) software, Solidworks 2016.
– Manufacture the model using additive manufacturing techniques.
– Simulate the rotational speeds of the servomotors using Proteus Design Suite software.
– Connect the servomotor control system with Arduino.
– Integrate the mechanical and electronic parts to generate the prototype.

Theoretical reference

The origin of orthotic and prosthetic practice can be traced back to antiquity with early orthopaedic craftsmen using leather, textiles and metals as fabrication materials for splints and bone repair, based on humanity's physical need for functional and cosmetic integrity in response to limb loss (Edelstein and Bruckner, 2002).

Although these early practitioners were innovators in this area, during the 19th century their craft developed very slowly (LeTourneau Prosthetics, 2017), with significant records until 1905, when Whitman Brace invented the first full foot orthosis made of heavy metal (Bin, 2019). It was during World War I when the ten leading prosthetics firms in the United States met to determine the state of the art in prosthetic technologies and manufacturing methods, leading to the creation of the Artificial Limb Orthotics and Manufacturers Association, an event considered to be the turning point in the development of orthotics and prosthetics in this country (LeTourneau Prosthetics, 2017).

Between 1945 and 1976, the Veterans Administration, universities, private companies and other military research units were contracted to conduct numerous prosthetics and orthotics research projects (Thompson, 2019). Increased demand for services in orthotics and prosthetics led to improved components, materials and clinical skills from 1960 onwards (LeTourneau Prosthetics, 2017), with composite materials, such as fibreglass and thermoplastics, being introduced to the field (Terekho and Chistyakov, 2021). The field of prosthetics and orthotics is constantly changing, with newer technology and materials being incorporated into everyday practice, and research in the field is increasing as interest in restoring or simulating lost human function becomes more of a reality with scientific and technological advances (Kelly et al., 2007).

An emerging technology in the field of orthotic fabrication is additive manufacturing (contemplating 3D printing), which reduces part manufacturing costs by reducing material and time to market, as well as increasing design freedom, potentially resulting in weight savings and easier assembly (Williams et al, 2016). Additive manufacturing processes take information from a computer-aided design (CAD) file that is subsequently converted into a stereolithography (STL) file, in this process, the drawing made in the CAD software is approximated by triangles and slices, which contains the information of each layer to be printed (Wong and Hernandez, 2012). Multiple research and development of orthotics are currently related to additive manufacturing (Patel and Gohil, 2022; Brognara *et al*., 2022; Wang *et al*., 2020; Banga *et al*., 2020; Liu *et al*., 2019; Alqahtani *et al*., 2019 and Banga *et al*., 2018).

Another major technology that has been evolving since 2005 and permeating prototype development is the open-source electronics platform Arduino, which combines software and hardware for multiple functions, including control commands through reading input (a sensor or a button) and converting an output (turning on/off a motor or a lamp), which has enabled adaptation to new application needs and challenges, including 3D printing, the Internet of Things (IoT), wearables and embedded environments (Moreno and Córcoles, 2018).

For the purposes of dynamic orthotics fabrication, Arduino is used as a controller for actuators including servo motors; a rotary actuator that allows precise control of angular position, velocity and acceleration, consisting of a suitable motor coupled to a sensor to feedback position from a set of gears and a control board, with the ability to be placed in any position generally from 0 to 180° (Chhabra *et al*., 2015). Multiple research and orthotics development is currently related to Arduino integration and servo motor control (Narote *et al*., 2022; Ozsahin and Ozsahin, 2022; Kashizadeh *et al*., 2022; Aljobouri, 2022; Smajic and Duspara, 2021 and Hernandez *et al*., 2021).

Methodology to be developed

The basis of this research is based on the analysis of the biomechanics, architecture and functional patterns of the fingers of the hands, based on Peña *et al*. (2012), Arias (2012), Viladot and Ruano (2001) and Smith *et al*. (1992). The methodology used in the development of the prototype is based on Becker Orthopedic (2022), Yung *et al.* (2018), Merchant *et al*. (2018), Palousek *et al*. (2014), Boyard *et al*. (2014) and Gehlot et al. (2018). This research has 6 main stages, described below:

Stage 1: Test subject selection. In this stage, a female subject was chosen to design the dynamic orthosis, based on the geometric and dimensional considerations of her hand. It is worth mentioning that the test subject does not present any type of injury, malformation or disability in her hand (healthy test subject).

Stage 2: Dimensional measurement of the test subject's hand. In this stage, with the help of a tape measure and paper replicas of the morphology of the test subject's hand, the dimensional data of the entire structure of the subject's right hand was obtained (Figure 1), following the methodology of Becker Orthopedic (2022).

Figure 1 Some dimensional measurements of the test subject's hand

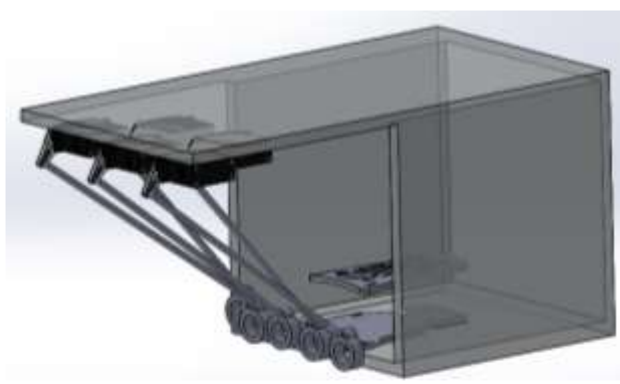

Figure 2 Mechanism assembly in Solidworks software

Stage 3. Design of the mechanism in Solidworks software. Once the dimensions and tolerances of the test subject's hand were collected, the mechanism was designed in CAD using Solidworks software (Figure 2), applying the joint methodology of Merchant *et al*. (2018) and Palousek *et al*. (2014). The elements of the assembly are shown in Table 1.

Name of the part	Quantity
Lower bra	1
Upper clamp	1
Holding ring 1 (Thumb)	1
Holding ring 2 (Index, middle and ring finger)	3
Holding ring 3 (Little finger)	1
Cylindrical holder 1	1
Cylindrical support 2	2
Cylindrical support 3	2

Table 1 Integral elements of the dynamic orthosis mechanism

Stage 4. Manufacture of the final assembly. Each of the parts designed in CAD were passed directly to the MakeBot® software for additive printing simulation (Figure 3). Once the simulation parameters had been analysed and validated, each of the parts mentioned in Table 1 (Figure 4) were printed, based on the methodology used by Boyard *et al*. (2014). As a result, 2 parts printed in PLA material were obtained (Figure 5).

Stage 5. Electronic simulation and commissioning of servomotors. For this stage, the Proteus Design Suite software was used to determine the rotation and speed of the servomotor axes (Figure 6), using the methodology employed by Gehlot *et al*. (2018). Once the software simulation was analysed and validated, the circuit was physically integrated through Arduino (Gehlot *et al*., 2018).

Stage 6. Assembly of mechanical and electronic components. Once the parts that make up the mechanism were printed, the orthosis was assembled based on the design in Figure 2. The placement of the servomotors coincided with the distribution of the fingers and the length of the phalanges of the test subject's hand. To attach the rings to the servomotors, PLA cylinders were used, whose function is to make a linking connection to the phalanges of the hand, and thus to transmit the movement from the servomotor to the fingers. To join the lower and upper fasteners, "Velcro" was used as an adhesive material, recommended by Fitzgerald *et al*. (2004), as well as being economically viable and easy to remove (Figure 7).

Figure 3 Manufacture of individual parts in PLA material with AXIOM printer. ®

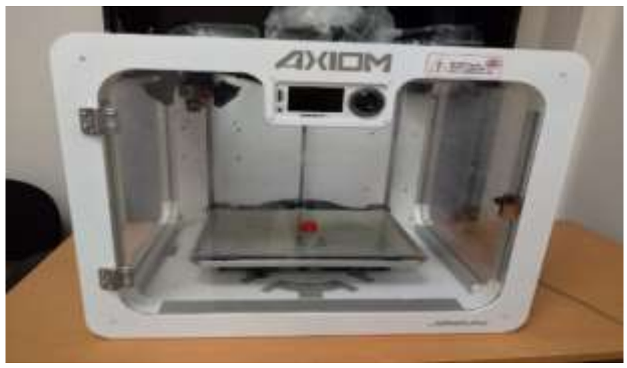

Figure 4 3D printing of the upper bra at AXIOM

Figure 5 Manufacture of individual parts in PLA material with AXIOM printer

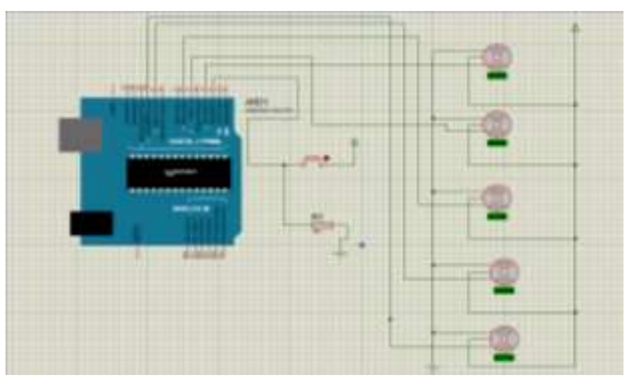

Figure 6 Simulation of rotational speed in servomotors with Proteus Design Suite, with Arduino Nano controller

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Figure 7 Upper and lower fastener connections with "velcro"

Results

Based on the literature on the functional biomechanics of the hand, a prototype of a dynamic orthosis with one degree of freedom in the phalanges of the fingers was fabricated. The degree of freedom corresponds to the flexion/extension movement of the fingers. This movement is realised by means of a simple linkage mechanism, consisting of rigid fasteners (links), anchored to the servomotor shaft, and directly connected to the rings for the transmission of movement to the fingers. The 180° circular motion of the servomotors generates a linear motion in the rigid fasteners, allowing flexion/extension motion in the fingers.

The prototype was used by the test subject to perform some measurements, which involved measuring the angles formed by the fingers when the fingers are extended (open hand). In this situation the measurements were as follows: separation between thumb axis and index finger = 44°, index finger and middle finger = 22°, angle formed by the third and fourth finger = 19°, and, finally, angle formed by the fourth and fifth finger = 21°, all values agreeing with (Smith-Agreda, Ferres and Montesinos, 1992), with a margin of error of less than 5%. In the flexion measurements (closed hand), it was observed that the mechanism performs an inclination in the fingers of almost 90° in the index finger, with an increase in the lateral fingers as it approaches the little finger, coinciding with the information analysed in (Viladot and Ruano, 2001).

Qualitatively, it was observed that the movement made by the rigid links between the rings and the servomotor axes generate a movement very similar to that of the biomechanics of the hand, however, this alters as the speed of the motor increases. The prototype is shown in Figure 8.

Figure 8 Prototype dynamic orthosis

Conclusions

A dynamic hand orthosis helps the recovery of the hand when it suffers an accident that compromises the correct functionality of bones, muscles, ligaments and/or tendons. To help more people with physical disabilities, the manufacture of assistive devices based on simple and inexpensive technology is essential for the field of rehabilitation, especially in developing countries such as Mexico.

In this study, a prototype of a dynamic hand orthosis made from 3D printing was presented. The innovation of this prototype consisted in the movement of flexion and extension in an assisted manner, that is, automatically by means of a mechanism controlled by servomotors with limited rotation, for those cases where the user has no movement in the phalanges and thus prevents the muscles from atrophying. The contribution of this research is the development of an economical device that can partially or completely replace the physiological therapies of a patient with upper limb (hand) problems.

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With the help of a physiotherapist, important decisions can be made to decide the type of therapy that can be performed with this orthosis system and thus make the required modifications to the prototype; selection of materials, programming, sizing and actuators, to name a few, all to meet the needs of the patient.

It is important to note that the prototype is currently programmed for the fingers to move simultaneously, however, the code is flexible and the servomotors could be programmed to move one at a time, two at a time or any combination required, as each case is different, and therefore with different needs. These configurations can be added through a selector (a button or knob, for example) to suit the user's needs. Although the long-term usability of the prototype has not been evaluated, it is hoped that future optimisations with the help of professionals in the field can benefit users with injuries to other body parts and its possible application in clinics and hospitals. This research is still at an early stage, however, the prototype dynamic orthosis developed from 3D printing and electronic actuation devices appears to be cost-effective and promising for use as an alternative to conventional rehabilitation technologies and techniques.

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Article

Journal of Technological Prototypes

December 2022 Vol.8 No.22 30-35

Mechanical characterization of tin coatings with biomedical application in elbow prostheses

Caracterización Mecánica de recubrimientos tin con aplicación biomédica en prótesis de codo

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DOI: 10.35429/JTP.2022.22.8.30.35 Received September 17, 2022; Accepted December 15, 2022

Abstract

The present work aims to study TiN films deposited on AISI 316L stainless steel substrates by physical vapor deposition through the Magnetron Sputtering technique with CD, heating it at a temperature of 200º and a constant time of 30 min. Identifying the mechanical properties to be used in biomedical applications, the microstructural characterization was performed by Optical Microscopy (OM) and Scanning Electron Microscopy (SEM). Adhesion tests were performed under the VDI 3198 standard. Tribological wear tests were performed using a 6 mm chromium plated steel pin (AISI 52100) on coated and uncoated substrates to study and compare the sliding effect continuing the same circumferential geometry, with a stroke length of 200 m and a load of 5N in wet and dry way using milli-Q water to simulate biological fluids in order to test the performance and durability of the implant.

Biomedical application, Properties, Sputter deposition

Resumen

En el presente trabajo se busca estudiar películas TiN depositadas sobre sustratos de acero inoxidable AISI 316L mediante la deposición física de vapor a través de la técnica Magnetron Sputtering con CD, calentándolo a una temperatura a 200º y un tiempo constante de 30 min. Identificando las propiedades mecánicas para ser utilizadas en aplicaciones biomédicas, la caracterización microestructural fue realizada mediante Microscopio Óptico (OM) y Microscopia Electrónica de Barrido (MEB). Las pruebas de adhesión se realizaron bajo la norma VDI 3198. Las pruebas de desgaste tribológico se realizaron utilizando un pin de acero cromado de 6 mm (AISI 52100) en los sustratos recubiertos y sin recubrir para estudiar y comparar el efecto de deslizamiento continuando la misma geometría circunferencial, con una longitud de carrera de 200 m y una carga de 5N en vía húmeda y en vía seca utilizando agua milli-Q para simular los fluidos biológicos con el fin de probar el desempeño y durabilidad del implante.

Aplicaciones Biomédicas, Propiedades, Depósito por Sputter

Citation: CABRERA-ROSAS, Yazmin, MELO-MÁXIMO, Lizbeth, MELO-MÁXIMO, Dulce Viridiana and ÁVILA-DAVIAL, Erika Osiris. Mechanical characterization of tin coatings with biomedical application in elbow prostheses. Journal of Technological Prototypes. 2022. 8-22: 30-35

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Introduction

Surface engineering has allowed over the years of its research, study and analysis to create processes through different techniques, which provide the alloy of materials with better properties for different applications in human life, as part of these processes is the manufacture of coatings, capable of maintaining the mechanical properties of the materials in contact with another surface, that is, to maintain the volume of the coated material without losing its qualities, what we know as wear resistance. From railway tracks to medical implants, different variants have been generated in thin film components, being titanium, chromium and steel the protagonists as biocompatible substrates. [1] In this way, disciplines such as traumatology and orthopedics have benefited from this advance by giving a second chance of a full and independent life to those who have been affected by a congenital problem or an accidental injury in shoulder, elbow, wrist, hip or knee joints.

Within the upper trunk, the elbow is a fundamental joint for the functioning of the upper extremities, since movements such as flexion-extension and rotation manage to bring the hand to the head, back and the rest of the body, at the same time it is defined as the load transmission joint. [2] Circumstances such as a distal humerus fracture, where they alter the architecture, increase stiffness or instability and allow pain, only result in limitations for daily activities.

By studying and understanding the biomechanics of the elbow has allowed researchers to develop joint replacements, and surface engineering through physical vapor deposition (PVD) by means of the Magnetron Sputtering technique [3], generate thin films capable of coating such prostheses and improve their performance and service life; this technique consists of transporting ionized electrons to the substrate to coat it and thus generate the thin film with the best variables [4] to maintain optimal mechanical properties, which are studied and analyzed by means of microstructural, mechanical and tribological characterization to ensure that the patient avoids readmission to the hospital. [5]

1. Experimental Development

Deposition Process. Titanium nitride films were deposited on AISI 316L stainless steel substrates previously prepared through coarse polishing, obtaining a mirror-like finish through fine polishing with diamond paste. See figure 1.

Figure 1 Samples with mirror finish

Subsequently, the samples were placed in the reactor (see figure 2) individually approximately 3 cm apart, it is worth mentioning that before starting the deposition time, the chamber was evacuated and then Ar (99. 997% pure) was introduced at a flow rate of 20 sccm, 997% pure) at a flow rate of 20 sccm and it was until the pressure stabilized that a power of 110 W was applied to the magnetron to start the plasma, the cleaning of the target was performed for 5 min, then the pressure was reduced to 2 Pa and the sample was placed above the target, increasing the pressure 150 W and integrating N at a flow rate of 5 sccm and so for 25 min. for a total time of 30 min. See Table 1. After deposition, the samples were left inside the reactor to cool before extraction. Four similar films were produced in terms of temperature and time parameters, the latter with the exception of sample 3 whose time was 35 min.

Parameters	
Substrate	316L
Substrate Temperature	200º
Initial Pressure	8.7 x10^{-4} torr
Working pressure	2 Pa
Ar	20 sccm
N	5 sccm
Power Supply	150 w
Objective	TiN
Deposition time	30 min

Table 1 Deposition parameters. [6]

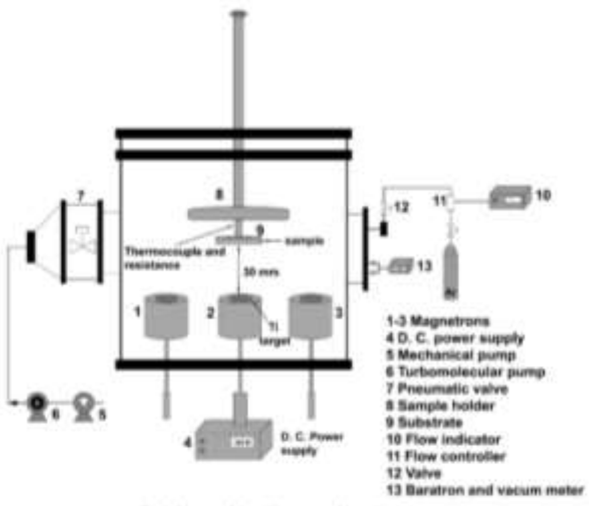

Figure 2 Diagram of deposition process and its components. [7]

Figure 3 316L stainless steel substrates after Ti/TiN deposition by PVD

2. Structural Characterization.

The TiN films were first analyzed by scanning electron microscopy using a Jeol JSM-6360LV equipment to obtain the morphology, the elemental composition of the surface by energy dispersive spectroscopy (EDS) in wet and dry way, also the wear traces on the steel pins were analyzed by optical microscopy in order to observe the wear caused by the effect of the tribological test.

3. Mechanical and tribological characterization in wet and dry way

Figure 4 shows the indentation obtained using a diamond tip and a load of 150 kg on the coated substrate, under the VDI 3198 standard to determine the degree of detachment of the film. Among the destructive tests this is used for coated composite materials whose coating may have a rupture due to deformation on the substrate. In the optical microscope we can see that, according to the contact geometry coupled with the shear caused by the intense load transfer, the film withstood the stresses and avoided delamination at the circumference of the print. While the radial cracks indicate strong adhesion, it is certain that brittleness is present.

It is worth mentioning that this sample was subjected to a wet wear test.

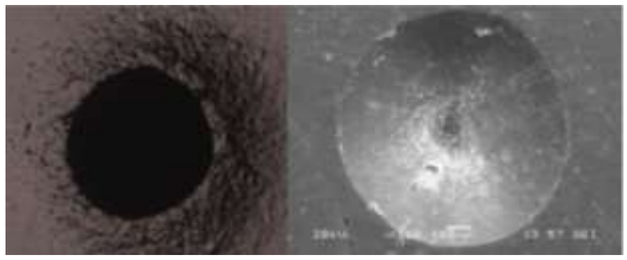

Figure 4 Footprint left on substrate and film by adhesion test under VDI 3198, on the left image taken with optical microscope, on the right image taken with scanning electron microscope

In Figure 5 we observe that in one of the samples that was studied dry and subjected to wear test, the delamination is notorious and even on the upper right side the film is visibly detached, exposing the substrate.

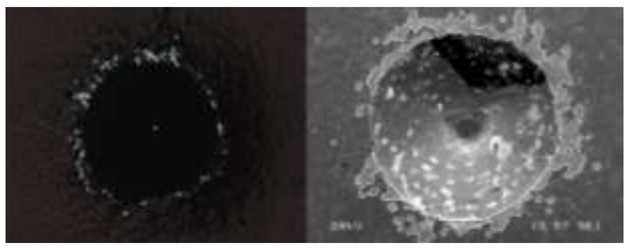

Figure 5 Test Standard VDI 3198, on the left image taken with optical microscope, on the right with scanning electron microscope

The tribological behavior of the samples was analyzed through the tribological pin-on-disk test with a 6 mm chromium-plated steel pin (AISI 52100) (see Figure 6). All tests were performed under the ASTM G99 standard test method which is a standard test method for wear tests with a pin-on-disk machine. These were performed on coated and uncoated 316L stainless steel substrates to study and compare the effect of sliding in the same circumferential geometry, with a stroke length of 200 m and a load of 5N in wet and dry path using milli-Q water to simulate biological fluids in order to test the performance and durability of the implant.

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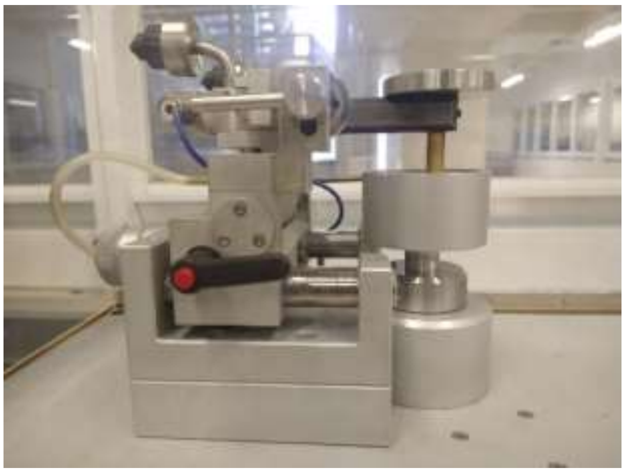


Figure 6 CSEM Tribometer, model 18-259 with which the tribological test was performed

By means of the pin-on-disk wear test, information on the coefficient of friction (COF) of each of the Ti/TiN films was collected and plotted against the stroke distance of each of the samples analyzed in the tribological wear test, allowing us to appreciate the behavior and comparison between the tribological fingerprints of both the samples and the pin under the given conditions, either in wet or dry conditions. As shown in Figures 7 and 8

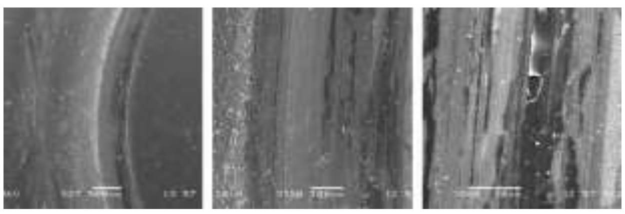


Figure 7 Tribological footprint in 316L/Ti TiN in dry process

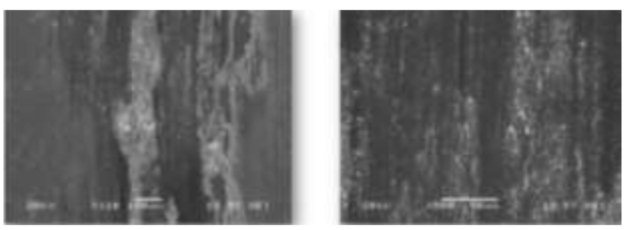


Figure 8 Tribological footprint in 316L/Ti TiN in wet process

A correlation was observed between the wear of the samples and the pin in terms of the friction coefficient. Figure 9 shows the acceptable wear pattern due to the thin film and the humid environment in which the test was carried out.

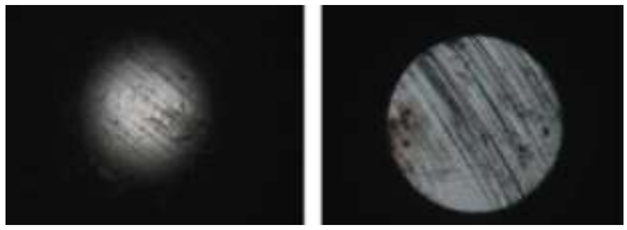


Figure 9 Chrome-plated steel pellet used in the wet wear test on Ti/TiN coated 316L substrate, on the left before the test and on the right side after the test

In comparison with the wear track on the pellet exposed to the same conditions with the difference that the substrate was not coated, the track shows a more pronounced depth thanks to the contact it had with the substrate as can be seen in Figure 10.

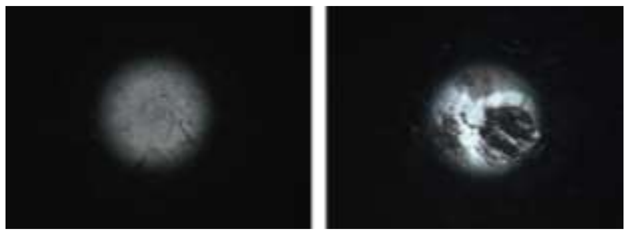


Figure 10 Chromium-plated steel ball used on the uncoated 316L steel substrate in the wet wear test, left side before the test and right side after the test

While the results in the dry test with the uncoated substrate show a ball with defined but not very uniform scratches, in comparison with the sample with the film, where in spite of not having a lubricant, defined and uniform scratches are observed due to the uniform wear given by the same coating. Figures 11 and 12.

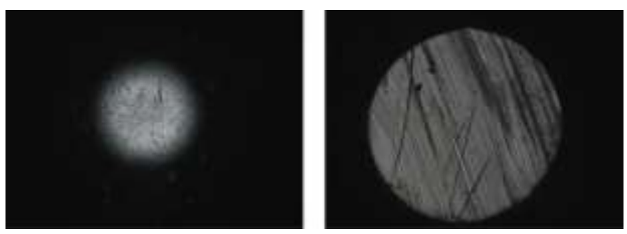


Figure 11 Chrome-plated steel ball used on uncoated 316L steel substrate in the dry wear test, left side before the test and right side after the test

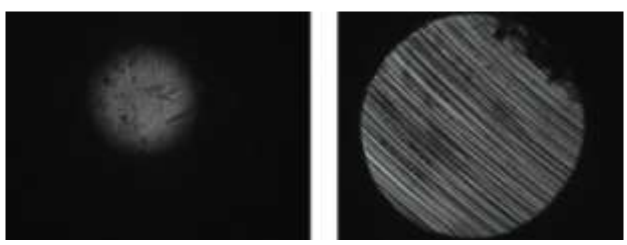
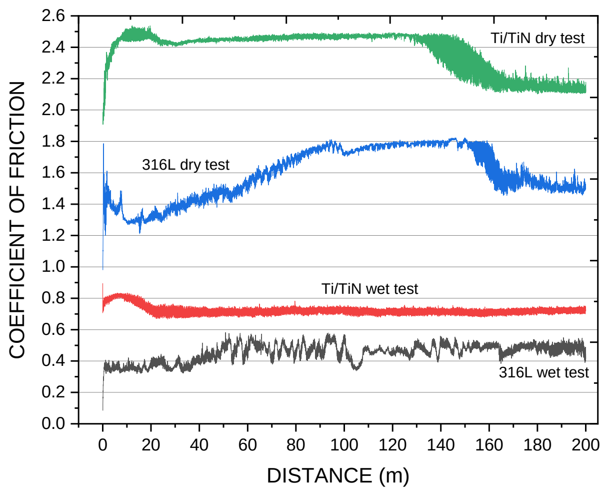


Figure 12 Chrome-plated steel ball used in the dry wear test on TiN-coated 316L substrate, on the left side before the test and on the right side after the test

Obtaining that, the highest wear is observed in the 316L substrate in dry way, thanks to the inexistence of a coating and a lubricant, in comparison with the sample coated with Ti/TiN in wet way which had the lowest COF. It is worth mentioning that there is not an important difference between the COF of the coated substrate and not in dry way, because in the graph they have a parallel run and increase. It is important to mention that the polished substrate subjected to the wet test had a perpendicular behavior from 120 m and increased its COF after this distance, showing the performance of the thin film. Graph 1.



Graph 1 Tribological behavior (COF)

4. Acknowledgements

To the TecNM/ITTLA for the opportunity to carry out this research, to the Surface Engineering Laboratory at the Tecnológico de Estudios Superiores Campus Estado de México for the facilities granted.

To the Network "Laboratorio Nacional del TECNM para impulsar la I+D+I en Ingeniería" for the collaboration.

To COMECYT-FICDTEM-2021-038 for the funding granted for this project, as well as to CONACYT for the National grant awarded.

5. Conclusions

The deposition process was successfully carried out in each of the samples, obtaining a homogeneous titanium nitride film.

The structural, mechanical and tribological characterization showed a coating with acceptable failure, low delamination on the edges of the identation when subjected to load based on the VDI 3198 standard, having an acceptable adhesion, while its tribological behavior was as expected, having a lower COF (coefficient of friction) in a wet way and in a 200 m stroke, unlike the uncoated substrate and in a dry way.

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ISSN: 2444-4995

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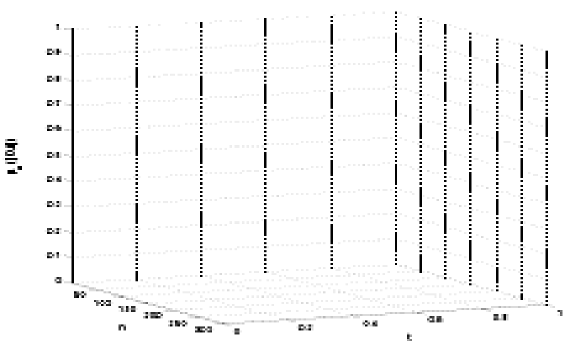

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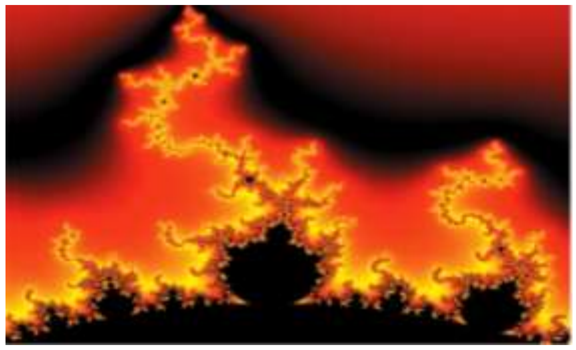

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ISSN 2444 - 4995
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