Tekhnê

Tecnología al servicio de la sociedad

Universidad Distrital Francisco José de Caldas - Facultad Tecnológica

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Cubierta: Hunting Diana, Szczytnicki Park, Wrocław (Polonia)
Autor: Fredy H. Martínez S.

Contracubierta:
• Superior izquierda: Solution designed for support structure and drum (Paez, A. and Gómez, D.)
• Superior derecha: Final software assembly of the anthropomorphic prototype (Hernández, D. and Lee, R.)
• Centro: Magnetic field lines (Rodríguez, J. and Díaz, F.)
Inferior izquierda: Digital ecosystem model for virtual education at CONALTEL (Ospina, Y. and Galvis, J.)
• Inferior derecha: Sample plot of function Rqt_Plot (Moreno, A., and Páez, D.)

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Revista Tekhnê

La revista Tekhnê es una publicación institucional de la Facultad Tecnológica de la Universidad Distrital Francisco José de Caldas. Posee un carácter científico, y atiende a la comunidad nacional e internacional especialista en áreas de ingenierías eléctrica, electrónica, mecánica, de sistemas, industrial y civil. Publica resultados de investigación en inglés (artículos originales e inéditos), y está completamente abierta a especialistas de todo el mundo en calidad de autores y/o lectores. Es arbitrada mediante un proceso doble ciego, con rotación continua de árbitros. La periodicidad de la conformación de sus comités Científico y Editorial está sujeta a la publicación de artículos en revistas indexadas internacionalmente por parte de sus respectivos miembros.

Periodicidad

La revista Tekhnê posee una periodicidad semestral, coincidente con los semestres académicos de la Universidad Distrital. La publicación se realiza los meses de julio y diciembre. El primer volumen de la revista se publicó el primer semestre de 2003, manteniendo su regularidad hasta la fecha.

Misión

La revista Tekhnê tiene como misión divulgar resultados de investigación realizados en el área de la ingeniería, a través de la publicación de artículos originales e inéditos, realizados por académicos y profesionales pertenecientes a instituciones nacionales o extranjeras del orden público o privado. Propende por la difusión de resultados y su acceso abierto y libre.

Público objetivo

La revista está dirigida a docentes, investigadores, estudiantes y profesionales interesados en la actualización permanente de sus conocimientos y el seguimiento de los procesos de investigación científica en el campo de la ingeniería.

Forma de adquisición

La revista Tekhnê se puede adquirir a través de compra, canje o suscripción.

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Author: Fredy H. Martínez S.

Back cover picture:
• Top left: Solution designed for support structure and drum (Paez, A. and Gómez, D.)
• Top right: Final software assembly of the anthropomorphic prototype (Hernández, D. and Lee, R.)
• Middle: Magnetic field lines (Rodríguez, J. and Díaz, F.)
Lower left: Digital ecosystem model for virtual education at CONALTEL (Ospina, Y. and Galvis, J.)
• Lower right: Sample plot of function Rqt_Plot (Moreno, A., and Páez, D.)

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Tekhnê Journal

Tekhnê journal is an institutional publication of the Facultad Tecnológica of the Universidad Distrital Francisco José de Caldas. It has a scientific character and serves the national and international community specialized in the areas of electrical, electronic, mechanical, systems, industrial and civil engineering. It publishes research results in English (original and unpublished articles), and is completely open to specialists from around the world as authors and/or readers. It is arbitrated through a double-blind process, with continuous rotation of arbitrators. The periodicity of the formation of its Scientific and Editorial Committees is subject to the publication of articles in internationally indexed journals by their respective members.

Periodicity

Tekhnê journal is published every six months, coinciding with the academic semesters of the Universidad Distrital. It is published in July and December. The first volume of the journal was published in the first semester of 2003, maintaining its regularity to date.

Mission

The mission of Tekhnê journal is to disseminate research results conducted in the area of engineering, through the publication of original and unpublished articles by academics and professionals belonging to national or foreign institutions of public or private order. It aims at the diffusion of results and their open and free access.

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Form of adquisition

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Declaración de ética y buenas prácticas

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Revista Tekhnê
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El comité editorial de la revista Tekhnê está comprometido con altos estándares de ética y buenas prácticas en la difusión y transferencia del conocimiento, para garantizar el rigor y la calidad científica. Es por ello que ha adoptado como referencia el Código de Conducta que, para editores de revistas científicas, ha establecido el Comité de Ética de Publicaciones (COPE: Committee on Publication Ethics) dentro de los cuales se destaca:

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- Propender por el mejoramiento continuo de la revista.
- Asegurar la calidad del material que se publica.
- Velar por la libertad de expresión.
- Mantener la integridad académica de su contenido.
- Impedir que intereses comerciales comprometan los criterios intelectuales.
- Publicar correcciones, aclaraciones, retractaciones y disculpas cuando sea necesario.

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La revista incluye una descripción de los procesos seguidos en la evaluación por pares de cada trabajo recibido. Cuenta con una guía de autores en la que se presenta esta información. Dicha guía se actualiza regularmente y contiene un vínculo a la presente declaración ética. Se reconoce el derecho de los autores a apelar las decisiones editoriales.

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Tekhnê asume su obligación para actuar en consecuencia en caso de sospecha de malas prácticas o conductas inadecuadas. Esta obligación se extiende tanto a los documentos publicados como a los no publicados. Los editores no sólo rechazarán los manuscritos que planteen dudas sobre una posible mala conducta, sino que se consideran éticamente obligados a denunciar los supuestos casos de mala conducta. Desde la revista se realizarán todos los esfuerzos razonables para asegurar que los trabajos sometidos a evaluación sean rigurosos y éticamente adecuados.

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En caso de detectarse algún trabajo cuyo contenido sea fraudulento, será retirado tan pronto como se conozca, informando inmediatamente tanto a los lectores como a los sistemas de indexación.

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Tekhnê establecerá los mecanismos necesarios para evitar o resolver los posibles conflictos de intereses entre autores, evaluadores y/o el propio equipo editorial.

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Cualquier autor, lector, evaluador o editor puede remitir sus quejas a los organismos competentes.

Code of ethics and good practice

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The editorial board of Tekhnê journal is committed to ethics high standards and good practice for knowledge dissemination and transfer, in order to ensure rigour and scientific quality. That is why it has taken as reference the Code of Conduct, which has been established by the Committee on Publication Ethics (COPE) for scientific journal editors; outlining the following:

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As most responsible for the journal, Tekhnê committee and the editorial board are committed to:

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- Tending to the continuous improvement of the Journal.
- Ensuring quality of published material.
- Ensuring freedom of expression.
- Maintaining the academic integrity of their content.
- Prevent commercial interests compromise intellectual standards.
- Post corrections, clarifications, retractions and apologies when necessary.

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The journal includes a description of the process for peer evaluation of each received work, and has an authors guide with this information. The guide is regularly updated and contains a link to this code of ethics. The journal recognizes the right of authors to appeal editorial decisions.

Publishers will not change their decision in accepting or rejecting articles, unless extraordinary circumstances or irregularities are detected. Any change in the editorial board members will not affect decisions already made, except for unusual cases where serious circumstances converge.

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Tekhnê makes available to reviewers a guide to what is expected from them. Reviewers identity is protected at all times, ensuring anonymity.

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Tekhnê ensures that material submitted for publication will be considered private and confidential issue while being reviewed (double blind).

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Tekhnê is committed to respond quickly to complaints and ensure that dissatisfied claimant can process all complaints. In any case, if applicants fail to satisfy their claims, the journal considers that they have the right to raise their protests to other instances.

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Tekhnê accepts the obligation to act accordingly in case of suspected malpractice or misconduct. This obligation extends both to publish and unpublished documents. The editors not only reject manuscripts with doubts about possible misconduct, but they are considered ethically obligated to report suspected cases of misconduct. From the journal every reasonable effort is made to ensure that works submitted for evaluation are rigorous and ethically appropriate.

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Tekhnê will establish the necessary mechanisms to avoid or resolve potential conflicts of interest between authors, reviewers and/or the editorial board itself.

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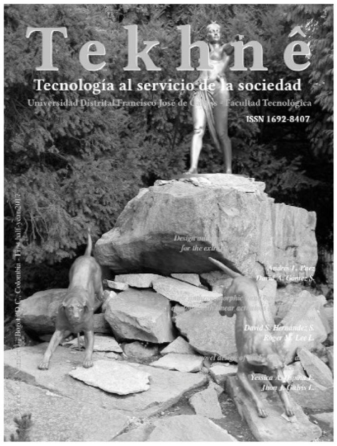
Any author, reader, reviewer or editor may refer their complaints to the competent authorities.



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Editorial

Próximamente, en tan solo un par de meses, la Alcaldía de Bogotá hará entrega oficial a la ciudad de la Ciudadela Universitaria El Porvenir en Bosa. Esta corresponde a una nueva sede de la Universidad Distrital Francisco José de Caldas, que gracias a su política de infraestructura descentralizada y distribuida en busca de equidad social, es capaz de ofrecer programas universitarios de alta demanda y calidad en todos los rincones de la ciudad. Ya con anterioridad lo había hecho con la Facultad Tecnológica (Ciudad Bolívar al sur de la ciudad) y con la Facultad de Artes ASAB (barrio La Capuchina en el centro de la ciudad), y esta vez lo hace en esta localidad con la idea de promover el acceso a la educación superior para alrededor de 6.000 jóvenes en estratos 1, 2 y 3.

Se espera que en agosto de este año inicien las clases en esta sede con los programas académicos de Administración Deportiva, Ingeniería Sanitaria, Gestión Ambiental y Administración Ambiental. En sus 28.374 metros cuadrados construidos alberga un total de 55 salones, una biblioteca especializada, auditorios, y varios laboratorios especializados entre otros espacios. Se espera que la ciudadela se convierta en un modelo integral de formación, gracias al diseño estructural que incluye además de la Universidad Distrital formación básica y media para promover la continuidad de los procesos educativos.

En este nuevo número de la revista deseamos agradecer a los árbitros por su excelente y oportuno trabajo evaluando los manuscritos postulados para publicación. Además, agradecemos a la Editorial de la Universidad Distrital Francisco José de Caldas por el acompañamiento brindado. Este número planteo un nuevo reto con miras a incrementar la visibilidad de la revista. Este numero se ha editado íntegramente en inglés, para lo cual se ha implementado la traducción especializada como una nueva etapa del proceso editorial. Esperamos que este esfuerzo redunde en mayor citación de los artículos y de la revista.

Ph.D(c) Prof. Fredy H. Martínez S.
Docente Facultad Tecnológica
Universidad Distrital Francisco José de Caldas

Editorial

Soon, in just a couple of months, the Mayor's Office of Bogotá will officially present to the city of Ciudadela Universitaria El Porvenir in Bosa. This corresponds to a new campus of the Universidad Distrital Francisco José de Caldas, which thanks to its policy of decentralized and distributed infrastructure in search of social equity, is able to offer university programs of high demand and quality in all corners of the city. It had previously done so with the Facultad Tecnológica (Ciudad Bolívar to the south of the city) and with the Facultad de Artes ASAB (La Capuchina neighborhood in the center of the city), and this time it does so in this locality with the idea of promoting access to higher education for about 6,000 young people in strata 1, 2 and 3.

It is expected that in August of this year classes will begin at this campus with the academic programs of Sports Administration, Sanitary Engineering, Environmental Management, and Environmental Administration. In its 28,374 square meters, it houses a total of 55 classrooms, a specialized library, auditoriums, and several specialized laboratories, among other spaces. It is expected that the citadel will become an integral model of education, thanks to the structural design that includes, in addition to the Universidad Distrital, basic and intermediate training to promote the continuity of educational processes.

In this new issue of the journal, we would like to thank the referees for their excellent and timely work in evaluating manuscripts submitted for publication. In addition, we thank the Editorial of the Universidad Distrital Francisco José de Caldas for the accompaniment provided. This issue posed a new challenge with the aim of increasing the visibility of the journal. This issue has been edited entirely in English, for which the specialized translation has been implemented as a new stage of the editorial process. We hope that this effort will result in a greater citation of the articles and the journal.

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Design and development of an electric winch for the extraction of vagonetes in a carbon underground mine

Diseño y desarrollo de un malacate eléctrico para extracción de vagonetas en una mina subterránea de carbón

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On this paper, the design of an electric winch to be used in an underground coal mine is shown. The design includes as background current mining methods, in order to compare their advantages and disadvantages. The formulation of the solution starts from the free body diagram of a full load wagon at the deepest point of the mine, from there, the forces acting on it are identified, and the tension is calculated in the steel cable. The design also includes the required protection and the control circuit for the motor starter. Under real operation in mine, we check the correct operation and performance of the prototype, fully being satisfied customer's need. In addition, the objectives were met 100%, fully meeting the proposed schedule.

Keywords: Electric winch, free body diagram, inclined plane, mining extraction

Éste artículo muestra el diseño de un malacate eléctrico para ser utilizado en una mina subterránea de carbón. El diseño contempla como antecedente los métodos actuales de extracción minera, a fin de comparar sus ventajas y desventajas. La formulación de la solución parte del diagrama de cuerpo libre de un vagón a plena carga en el punto más profundo de la mina, a partir de allí se identifican las fuerzas que actúan sobre éste, y se calcula la tensión en el cable de acero. El diseño contempla también las protecciones requeridas y el circuito de control para el arrancador del motor. Bajo operación real en una mina, se comprobó el correcto funcionamiento y desempeño del prototipo, satisfaciéndose completamente la necesidad del cliente.

Palabras clave: Diagrama cuerpo libre, extracción minera, malacate eléctrico, plano inclinado

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Introduction

Coal is a globally used energy resource. It is widely used for electricity generation, in the steel industry, and can be transformed into a crude oil similar to oil. Colombia has eight percent of the total percentage of the world in terms of coal deposits, extracted in large and small scale mining (Mejía, 2005).

Mineral deposits have been formed on land for millions of years under special conditions, mineral deposits are rare and are generally linked to anomalous geological structures (Bustillo & López, 1996).

Mining materials are non-renewable resources, which is why mining is an activity that must be managed responsibly in order to make the most of these limited resources (Hernández, Pedraza, & Martínez, 2016). Mining companies aim to achieve optimal extraction of mineral reserves with the greatest economic benefit and security of operations (Oyarzun & Oyarzun, 2011).

Depending on where the mineral deposits arise, different mining methods are used. Certain deposits are obtained in surface mines or open-cast mining, others with underground excavations that are accessed through tunnels (Virigilio, 2007).

The underground mining method is used when deposits are narrow, deep and covered with quantities of sterile material that make open pit mining economically unviable (Herrera & Gómez, 2007). Its method is based on building tunnels or galleries, to access the mineralized zones and result in the formation of a network of underground levels for production and transport from the interior of the mine to the plant, usually located on the surface (Herrera & Gómez, 2007).

To avoid landslides, the walls and the roof of the tunnel are stabilized, using an appropriate fortification for each type of terrain, which depends on the characteristics of this and the use it will be given. The classification of this type of mining is small, medium or large according to its annual production as follows:

- Metals and precious stones:
  - Small-scale mining up to 250,000 m^3/year.
  - Medium mining, between 250,000 and 1'500,000 m^3/year.
  - Large-scale mining, greater than 1'500.000 m^3/year.
- Coal:
  - Small-scale mining, up to 180,000 m^3 or 24,000 ton/year.
  - Medium mining, between 180,000 and 6'000,000 m^3 or between 24,000 and 800,000 ton/year.
  - Large-scale mining, greater than 6'000.000 m^3 or 800.000 ton/year.
- Other (excludes construction materials):
  - Small-scale mining, up to 100,000 tons/year (Muñoz, 2002).

For many countries, their economic base is focused on small-scale mining because of the low cost of labor and materials (Avila, 2000).

With transport in underground mining, the aim is to move the extracted ore to the outside of the mine. In old mining, the transport system used was baskets transported by people. Then the wheelbarrows were used. Later, in order to facilitate the rolling of these forklifts, aligned and leveled boards were installed, which can be considered as the beginning of the rails.

With the creation of metal rails and eyelash wheels and the use of animal power, greater loads could be moved with less effort. The use of cattle (horses, mules or oxen) was frequent, but teenagers or young children also worked on these tasks.

Gradually, the transport was mechanized, incorporating the technology developed with the arrival of the industrial era. Thus, the internal combustion locomotive and the electric locomotive made it possible to move ever-increasing weights, unthinkable with animal power (Sandoval, 2010).

In small-scale mining, the transport of mining material is done by means of winches, it is a rotating mechanical system, driven manually or by an engine that is used to drag, lift or move large loads such as minerals (ore, rock, coal, and others), personnel, tools, and supplies. It consists of a drum in which the steel cable is wound to which the means of transport is connected.

The use of conveyor belts is not suitable for this type of mining because of the angles of inclination at which it works. The maximum angles for optimum operation of a conveyor belt system are 25 degrees. Its main use is the transport of minerals into underground mines and not the extraction out of it.

Different techniques are used to extract coal in small-scale mines, ranging from human power (for very small loads) to internal combustion engines, which become unsafe and dangerous forms for both workers and the ecosystem.

This project seeks to technify the extraction of minerals in small-scale mines. The project is carried out for an underground coal mine in the municipality of Samacá, Boyacá (Colombia). We implemented an electric winch prototype for the extraction of the wagons (Martínez, Montiel, & Valderrama, 2016).

Problem formulation

Coal extraction at the Cochinillos mine

Samacá is a municipality located in the center of the department of Boyacá. The main economic activities of the municipality are agriculture, farming, and mining.

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The mining works have as main activity the underground exploitation of coal.

The Cochinillos coal mine is a one-man coal extraction company, located in the mining area of the municipality of Samacá, in the village of La Chorrera. The exploitation of the deposit is made in the subsoil, using the method of underground extraction or undermining, because the veins are narrow, deep and are covered with large quantities of sterile material. Company information is given in table 1.

Table 1
Technical data Cochinillos mine.

NIT	4.233.843
Exploitation license	LGD-14511 (31/072005)
Location	Vereda la Chorrera, municipality of Samacá, Boyacá (Colombia)
Economic activity	Coal Deposit Exploitation
Number of mine mouths	2
Monthly production	Approximately 336 tons
Daily production	Between 11 and 13 tons per mine mouth

Access to the coal seams is through tunnels that allow the transit of light wagons (Montiel, Jacinto, & Martínez, 2015). The ore is removed manually by drilling, using mechanical and pneumatic tools. The extraction of the mining material to the outside of the mine is carried out with wagons with a capacity of 1 ton coupled to a winch by means of a steel cable. Table 2 describes the extraction process of a coal mine.

The Cochinillos coal mine has two mine mouths, in which the main activities of the mining personnel are the chopping of coal, structural reinforcements, boat and transport of the mining material (Sandoval, 2010).

The mine has two mine mouths. The tunnels have a height of 1.8 m, a width of 1.7 m and distances between supports of 1 m. According to the norm, the minimum free area of a mining excavation must be three square meters with a minimum height of one meter and eighty centimeters (Díaz, 2015).

For mine two, where the project was developed, the slope angle is 35 degrees (in the worst case) and the length of the main slope is 100 m.

Table 2
Coal extraction process at the Cochinillos mine.

Process	Description
Preparation of the work site	Ventilation to the mine by means of a ventilation circuit. With a gas measuring instrument (Ventis MX4), the working atmosphere is verified by checking that it is within the permitted limits (Sandoval, 2010). The gases to be controlled are Methane (CH_4), Oxygen (O_2), Carbon Monoxide (CO) and Hydrogen Sulphide (H_2S).
Entering the mine	Staff walk in to the extraction site with all PPE for the activities to be performed.
Chopped	Chopping is carried out for the extraction of coal and rock manually (picks and shovels or with pneumatic hammers).
Support and maintenance of the mine mouth	The internal structure of the mine is supported with wooden doors to avoid collapses by internal pressure of the rocky massif. For the reinforcements is used wood of an approximate thickness of 20 cm and a height of 2 m.
Coal selection and sterile disposal	During the filling of the wagon a selection is made between coal and rock in order to avoid impurities. The rock is extracted from the interior of the mine in the same way as the coal and is gathered in the courtyard of the bocamina or placed in unattended work inside the mine.
Transport of the wagon into and out of the mine	For transport into the mine, the wagon coupled to the winch by means of a steel cable is lowered for transporting tools and supports. Inside the mine, the wagon filled with mining material is extracted to the surface. The interaction between the miner and the winch operator is done by means of a cytophone for communication related to the advance or stop of the wagon.
Transport and unloading of coal into the hopper	Already the wagon with mining material out of the mine, is dragged to the hopper where the coal is collected waiting to complete the loading of a dump truck between 11 and 13 tons of coal.
Load	The hopper load is emptied into a dump truck.
Transportation to sales site	When the dump truck is loaded it goes to the point of sale. In this place it is weighed and its quality of coal is determined, fixing with it the selling price.

Underground mining technologies

Manual mechanical winch. Use animal or human force to spin the drum that winds the steel cable. Material extraction times are long but discontinuous, so their use is limited to a few hours in the extraction time in the mine.

They are useful when the material to be extracted is very light and the drag does not exceed certain distance limits

(Fig. 1). Table 3 shows the main characteristics of a manual winch.

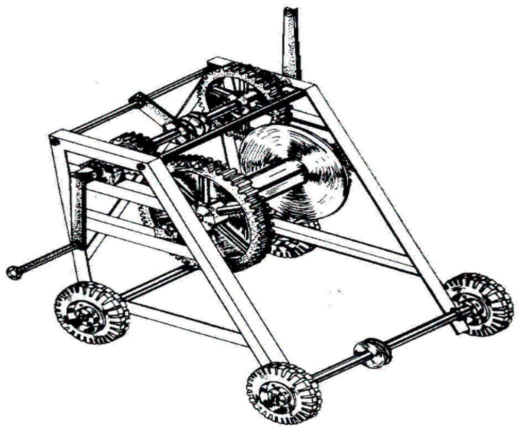

Figure 1. Manual mechanical winch (Ramos, 2004).

Table 3
Features of a manual winch.

Manual mechanical winch	
Application	Lifting and/or dragging of load
Capacity	5000 kg
Length	200 m
Transmission	Crown Endless
Lifting Speed	3 m/min
Drag time	33 min, to 100 m

Internal combustion winch. It is driven by an internal combustion engine that turns the mechanical system in charge of winding the steel cable coupled to the load. In small-scale mining this type of winches are built in an artisanal way, complete automobiles are used (Fig. 2), or sometimes the engine is removed to be adapted to a drum for spinning (Fig. 3). This system was initially used in the intervened mine. A video with its operation can be seen on: http://youtu.be/Zdk7xA6QyuE.

The practical use of this class of engines is given by their simplicity in installation and because they have completed their life cycle in the cars in which they were operating.

The consumption of fossil fuels as a primary energy source and oils or greases to lubricate mechanical elements generate negative impacts on the environment. These engines have a high drag capacity and have a gearbox to control the ascent and descent of the wagons. Table 4 shows the main characteristics of the winches used in the Cochinillos mine for the extraction of wagons.

The maintenance of this technology and the consumption of resources to guarantee its operation are costly. The useful life of these engines is low, affecting many times in the production of the mines.

Figure 2. Diesel tractor used for wagon extraction in an underground coal mine.

Figure 3. Petrol engine used for car extraction in an underground coal mine.

Table 4
Characteristics of the combustion winches in the Cochinillos mine.

Internal combustion winch		
Application	Lifting and/or dragging of load	
Engine	Diesel	Petrol
Automotive	Nuffeleld 1954 tractor	Dodge 1500
Power	45 Hp	90 Hp
Transmission	Mechanical	Mechanical
Drag time	6 min, to 100 m	6 min, to 100 m

The Cochinillos mine operates with two internal combustion winches, one for each mine mouth. The average fuel consumption for the tractor in the use of mining tasks is 0.92 gal/day and that of the gasoline engine is 1.38 gal/day.

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These depend on the operation of the mine and the daily production of coal or sterile.

Optimal operation of internal combustion winches requires preventive maintenance consisting of periodic oil changes, oil filters, and fuel filters.

Pneumatic winch. This device takes the power from a pneumatic head, which receives an air pressure, which is distributed alternately in its force plungers, generating a rotary power, which provides movement to the drum winding the cable, as well as consists of a braking band.

The pneumatic winches (Fig. 4) are ideal for use inside underground mines. They have a higher pulling force than other winches of the same size and because their energy source is air this helps the ventilation of the mines.

Figure 4. Pneumatic winch.

For optimum performance of pneumatic winches, they require preventive maintenance, which consists of general cleaning and verification of the level of lubricating oil in their mechanical parts. Table 5 shows the main characteristics of a pneumatic winch.

Table 5
Characteristics of Ingersoll Rand pneumatic winch.

Pneumatic winch	
Application	Lifting and/or dragging of load
Brand	Ingersoll Rand
Capacity	2000 kg
Lifting speed	25 m/min
Drag time	4 min, a 100 m
Air consumption	208 l/s
Pressure	0,6 - 0,8 Mpa
Power	16 Hp

Its installation is simple by means of hoses connected to an air compressor outside the mines, which can have electricity or diesel fuel as its main source of energy.

Compressors require preventive maintenance every 250 hours of work associated with oil change, oil filters, fuel filters, and compressor unit filters. Table 6 shows the main characteristics of the air compressor used in the Cochinillos mine for the operation of the tools (pneumatic hammers).

Table 6
Atlas Copco XAS 185 JD air compressor features.

Atlas Copco XAS 185 JD air compressor	
Air supply	151 - 185 l/s
Presión	0,7 - 1,4 Mpa
Power	49 Hp
Engine / John Deer	Diesel
Fuel consumption	1,2 gal/h, to full load

The air requirement of this tool is high, so it is necessary to have a large capacity compressor, which makes it difficult to apply in the small scale mine. Normally the air compressors drive hammers and pneumatic drills inside the mines with certain air consumptions, when connecting a pneumatic winch this consumes the air necessary for the operation of the other tools.

Electric winch. It uses the electrical energy in the motors to produce its mechanical energy in spinning the mechanical system in charge of winding the steel cable coupled to the load. There is a great variety of electric winches, single-phase and three-phase (Fig. 5). Magnetic brakes are added to these motors to keep the load in one position, in times when stops are made.

Figure 5. Electric winch with remote controls (Mattoli, n.d.).

They are ideal for outdoor use in underground mines, thanks to the few mechanical elements that compose them need little maintenance and do not generate carbon emissions that could enter the mine. Table 7 shows the main characteristics of an electric winch with a pulling capacity of 1.5 tons.

To make the most efficient use of electric motors, they are coupled to a speed reducer system to increase the necessary torque and decrease the power and size of the motors.

For the optimal functioning of the electric winches, the preventive maintenance that is carried out is general cleaning and verification of the level of the lubricating oil in its mechanical parts.

Table 7
Features of an electric winch.

Electric winch	
Application	Lifting and/or dragging of load
Capacity	1500 kg
Lift height	100 m
Lifting speed	22 m/min
Power	7,5 Hp
Brake	Electromagnetic discs
Voltage	208 V
Drag time	4 min, to 100 m
Electrical system	In metallic box with electrical circuit programmed with contactors and buttons for external control

Methodology and design

Calculation of stress

For the calculation of the stress to which the steel cable will be subjected, the wagon filled with coal at the deepest point of the inclined plane is considered, in order to consider the forces interacting on it (Fig. 6).

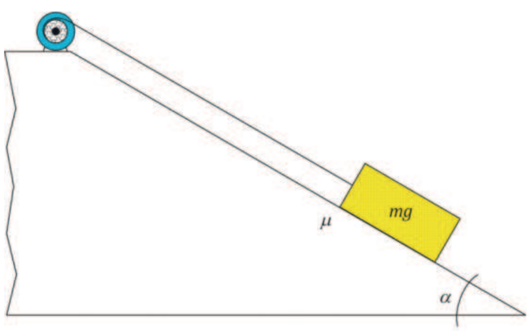

Figure 6. Inclined plane.

The forces acting on the fully loaded wagon at the incline of an underground mine are: the weight of the load, the weight of the cable at 100 m, the normal force of the load and the cable, the tension on the cable, the frictional force between the wheels of the wagon and the rail and the frictional force between the cable and the ground when pulled through the underground mine (Fig. 7).

The wagon (Fig. 8) is the means in which the mining material is transported, it is coupled with the winch by means of a steel cable. The one-ton wagon weighs 450 kgf, and we consider the weight of 100 m of cable.

$$W_V = m_V g = 1450\, kgf \tag{1}$$

$$G_S = 0,883\, \frac{kg}{m} \tag{2}$$

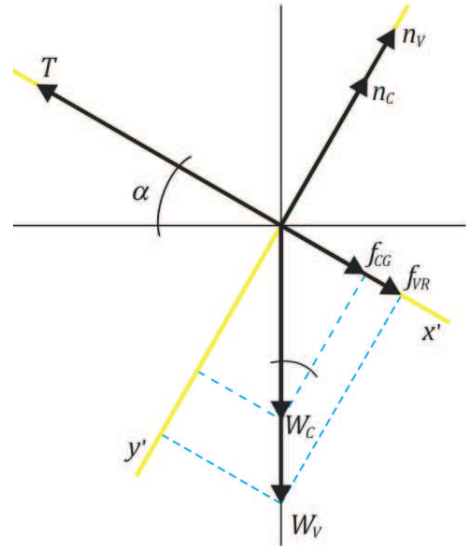

Figure 7. Free body diagram for wagon.

Figure 8. Mine wagon.

$$W_C = L \cdot G_S = 88,30\, kgf \tag{3}$$

The frictional forces interacting against movement occur by friction between the steel wheels and rails, and the steel wire rope dragged on the ground. To calculate the friction force between the steel wheels and the rails the coefficient obtained from Fig. 9, μ_1 = 0,2 at a speed of 0,06 km/h is used.

The coefficient μ_2 = 0,3 is selected to calculate the friction force of the steel wire rope dragged on the ground (Serway, 2003). In order to calculate the tension in the steel cable, the vectorial sum of all the forces interacting on the wagon is made.

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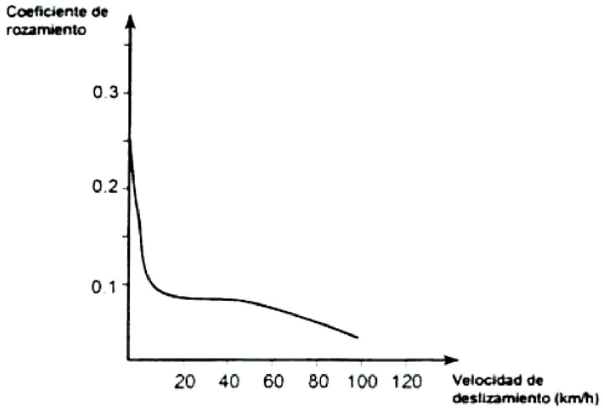

Figure 9. Average values of the coefficient of friction between steel wheel and rail (Álvarez & Luque, 2003).

$$\sum F_{x'} = T - W_V sin\, 35° - f_{VR} - f_{CG} - W_C sin\, 35° = 0 \quad (4)$$

$$\sum F_{x'} = T - W_V sin\, 35° - \mu_1 W_V cos\, 35° - \mu_2 W_C cos\, 35° - W_C sin\, 35° = 0 \quad (5)$$

$$T = W_V sin\, 35° + \mu_1 W_V cos\, 35° + \mu_2 W_C cos\, 35° + W_C sin\, 35° \quad (6)$$

$$T = 1128,26\, kgf = 11064,42\, N \quad (7)$$

Steel cable selection

A steel cable is a set of steel wires, stranded around a fiber core, which forms a metal rope suitable for resisting tensile stresses with appropriate flexibility qualities.

The steel cable connects the wagon with the motor reducer, this element must be able to support the total load. Its manufacture is under the following standards:

- American Petroleum Institute (A.P.I. Standard 9A)
- American Federal Specification (RR-W-410D)
- American Society For Testing & Materials (A.S.T.M.)
- British Standards Institute (B.S.)
- Deutsches Normenausschuss (D.I.N.)
- International Organization for Standardization (I.S.O.)

Serway (2003)

The following variables are taken into account for the proper selection of the cable:

Breaking load (resistance): Refers to the load that must be supported taking into account the static load, stop load, a sudden start. It is recommended to multiply the working load by a safety factor, indicated by the manufacturer.

Resistance to bending and vibration (fatigue): It happens when the cable is bent like in the pulleys. The lower the bending radius, the greater the fatigue action.

Abrasion resistance: It occurs when the cable rubs or is pulled against the ground and rollers.

Crushing resistance: The winding of the cable in several layers, on the drum.

Corrosion exposure: Because of the atmosphere, the cross-section decreases, the cables must be protected by periodic greasing (Ramos, 2004).

The cables used in mining operations are usually made of steel with breaking strength ranging from 140 to 180 kg/mm^2 (Ramos, 2004).

For cable selection, a safety factor is used taking into account the distance traveled (100 m) and the total load (W_V = 1450 kg). Table 8 presents the safety factors for steel ropes used in mining.

Table 8
Safety factors for steel cables used in mining operations (Icontec, 2004).

Depth [m]	Safety Coefficient	Replacement when it arrives
0-150	8	6,4
150-300	7	5,8
300-600	6	5,0
600-900	5	4,3
> 900	4	3,6

$$FS = \frac{True\, Resistance}{Required\, Resistance} \quad (8)$$

$$R_{True} = FS \cdot R_{Required} \quad (9)$$

Where *FS* is a safety factor for the weight to be supported by the cable (Fig. 10):

$$R_{True} = 2175\, kgf \quad (10)$$

The total load that the steel cable will support is:

$$T_r = T \cdot S = 2175 \cdot 8 = 17400\, kgf \quad (11)$$

Where:
- T: Total load or true resistance to which the cable is subjected.
- S: Safety coefficient.

Finally, the diameter of the drive cable is calculated:

$$d = k \cdot \sqrt{T} = 0,36 \cdot \sqrt{2175} = 15,85\, mm \quad (12)$$

Where k is the coefficient of rupture that is selected like this:

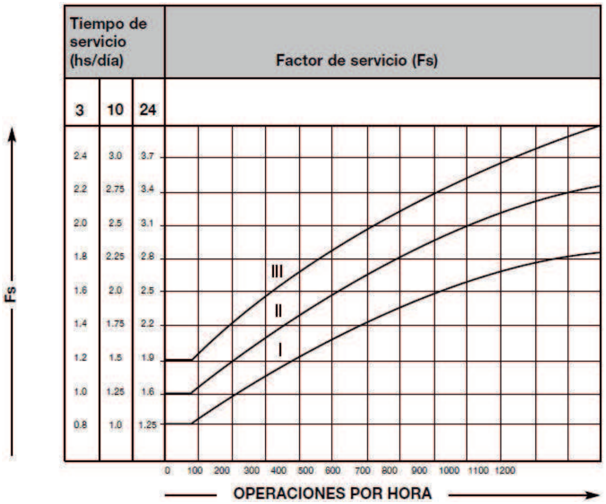

Figure 10. Safety factor (FS) (Emocables, 2013).

- 0,32-0,34 for the group I partial loads and frequent operation.
- 0,34-0,36 for the group II total loads and normal service.
- 0,36-0,38 for the group III total loads and frequent service.

According to these dimensions, the cable is chosen in agreement to the manufacturer and having the minimum breaking load (Icontec, 2004).

$$Breaking\ load = 17400\,kgf \cdot 9,8\,\frac{m}{s^2} = 170,52\,kgf \quad (13)$$

According to the manufacturer in Colombia, the cable selected was the steel cable with jute core, since it complies with the characteristics shown in table 9.

Table 9
Selected cable with manufacturer's data (Condori & Meléndez, 2015).

Diameter		**Minimum breaking load [kN]**	**Diameter range**	
[Inch]	[mm]		Min inch	Max inch
5/8	15,87	176	0,748	0,785

- Seale construction of 19 wires, more resistant to abrasion.
- Highly flexible fiber core with good tensile and compressive strength.
- Grease with very good adherence.

Other technical data that will help us in our calculations taken from the manufacturer:

- Approximate weight 0.883 kg/m.
- Minimum breaking load 150 kN, 167 kN.

Drum

In the drum the steel cable will be wound in an orderly manner, for which it must comply:

- Bending fatigue in a cable is an important variable and is related to the diameter of the drum.
- The diameter of the drum is calculated according to the characteristics of the cable.

$$D_T = s \cdot d \quad (14)$$

$$D_T = 16 \cdot 15,87 = 253,92\,mm \quad (15)$$

This value indicates the minimum diameter of the drum. The length of the drum is determined by defining a number of turns for the first layer, in this case, $L = 20$. The number of turns N is defined as:

$$D_T = 300\,mm \quad (16)$$

$$L = N \cdot \pi \cdot D_T \Rightarrow N = \frac{L}{\pi D_T} = 21 \quad (17)$$

For a cable diameter of d_c = 1,74 cm:

$$L_T = N \cdot d_c = 36,5\,m \approx 40\,m \quad (18)$$

The value is rounded to facilitate its construction. The weight of the cable for this amount of meters is important to establish the material of the drum and not suffer deformations during the time of operation. We established the following parameters:

$$W_C = Cable\ weight\left[\frac{kg}{m}\right] \cdot l_c \cdot g \quad (19)$$

Where:

- l_c: Total cable length.
- g: Gravity.

$$W_C = 840\,N \quad (20)$$

With a total of four turns, and the empty drum diameter plus 0,128 m (eight turns * 0,016) of cable accumulation, results in a full diameter of 0,428 m. Table 10 shows the length of cable wound over the drum per turn.

Table 10
Total cable wound on the drum.

1 turn	DT empty	21,67 m
2 turn	DT empty+0,032	23,98 m
3 turn	DT empty+0,064	26,30 m
4 turn	DT empty+0.128	30,95 m
Σ = 102,91 m		

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Gear motor

The gearbox is the mechanical equipment required to reduce motor speed to a safe level at working conditions, transferring power and amplifying effective torque to the load.

A gear motor is obtained by coupling an electric motor to the gear reducer which transmits the power of the motor to the driven machine complying with the principle of energy conservation, which tells us that the energy entering the system is equal to the energy leaving it plus the losses generated inside it.

In some cases, it is more important the moment of torsion that can give a reducer than the same power. The mechanical work that needs to be obtained is given by the torque.

For a proper selection, you must take into account the load to be moved, the torque required, the class of motor will carry the machine, and the speed of input and output of the reducer. For the tension in the drum, we define the torque in the gear motor shaft for a radius in the drum of 15 cm.

$$\tau = T \cdot r\ [Nm] = 11064,42 \cdot 0,15 = 1659,66\, Nm \quad (21)$$

The duty factor is a multiplier that indicates the degree of protection with which our speed reducer operates, it depends on the daily operating time and the type of service to which it will be subjected.

The mine has an eight-hour working day, seven days a week. With an average of six operations per hour of the winch and a class II load (Emocables, 2013), we selected a service factor of 1.25 (Fig. 10).

The required torque is defined as:

$$\tau_{Req} = \tau \cdot FS\ \ [Nm] = 1659,66 \cdot 0,25 = 2074,58\, Nm \quad (22)$$

Considering the synchronous speed of a four-pole motor and an efficiency of 91.7%, then:

$$v_{in} = \frac{120 \cdot f}{poles} = \frac{120 \cdot 60}{4} = 1800\, rpm \quad (23)$$

The output speed of the reducer with a ratio of 1:70 and an efficiency of 90.4% is:

$$v_{out} = \frac{v_{in}}{R} E_R = \frac{1800}{70} 0,904 = 23,24\, rpm \quad (24)$$

The efficiency of the gear motor is given by:

$$\eta = \frac{P_{out}}{P_{in}} \quad (25)$$

Pair on the shaft:

$$\tau_{Req} = \frac{P_{out}}{\omega_{s2}} \quad (26)$$

Input power:

$$P_{in} = \frac{P_{out}}{\eta} = \frac{\tau_{Req}\omega_{s2}}{\eta} = 5,51\, kw \quad (27)$$

$$P = 7,38\, Hp \quad (28)$$

Power and control circuits

In order to adequately protect this type of motor, adequate coordination of protections must be taken into account. Having determined all the components of the winch and knowing that the gear motor must comply with the operation of lifting, lowering and stopping the load, the force and control circuit is carried out according to the components available on the market. Complying with regulations, we carry out the following considerations:

Protection against fault current. This drift from the transformer or from the general board. It must be suitable protection that complies with the standard or according to the rating plate of these. They must be magnetic switches or fuses which are selected according to the manufacturer.

For magnetic type switches, they must comply with Table 430-151B of Locked Rotor. There are high currents approximately eight to 10 *In* of the motor, and it must not present a trigger by the presence of a short circuit, for that reason they lack thermal unit.

Overload protection. Thermal protection is implemented. This will be integrated to the motor or external to it. This one will present shot in presence of high currents in a short time, its action is almost instantaneous ("Motoreductores a sifín y corona", n.d.).

According to the motor nameplate:

- V_{in} = 208 V
- P_{in} = 7,5 [HP]

The current for selecting the appropriate protection is calculated as follows:

$$I_{in} = \frac{P\ [W]}{\sqrt{3}V_{in}} = 15,53\, A \quad (29)$$

By design we choose protection 1.25 times the nominal current, i.e. I_p = 19,41 A. We selected a magnetic switch with the following characteristics:

- Three-pole, moulded case, industrial type, 40 kA at 240 V, 36 kA at 400 V, fixed magnetic shot at 10 In, 20 A, Manufacturer: MEC.

We implement a direct starter with rotation inverter because it has a simple circuit for motor control, and we want to use easily accessible components.

Considering that the starting current of the motor varies from 5.6 to 8.4 *In*, the two types of starting are studied in order to choose the best option. For a direct start, the motor receives a direct voltage from the mains, which the starting torque is high and is used for motors starting with axle load. A reduced voltage start as its name suggests starts the motor at reduced voltage, the starting torque is reduced and is used for motors without a load on the rotor. With these considerations, we implement a direct starter with turn inverter (Fig. 11 and Fig. 12).

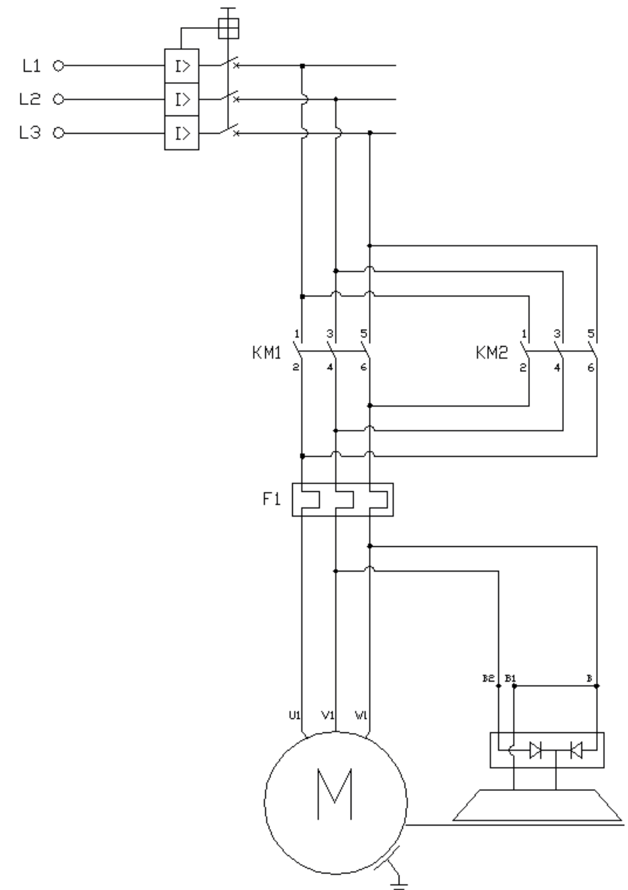

Figure 11. Force circuit.

This control board solution reduces peak currents at startup and mechanical wear of the drive.

The guidelines to follow after implementing this start is that the service transformer is sized for a start of these, the connection must be adequate to withstand the starting current, and have no voltage drop problems at the time of operation.

Economic evaluation

The implemented solution was analyzed from its costs assuming the direct purchase to the supplier and carrying out all the electrical assembly according to the unifilar by the designers. This included the delivery of plans and on-site tests (table 11).

The materials required were:

- A pulsating station.
- A three-pole magnetic switch.

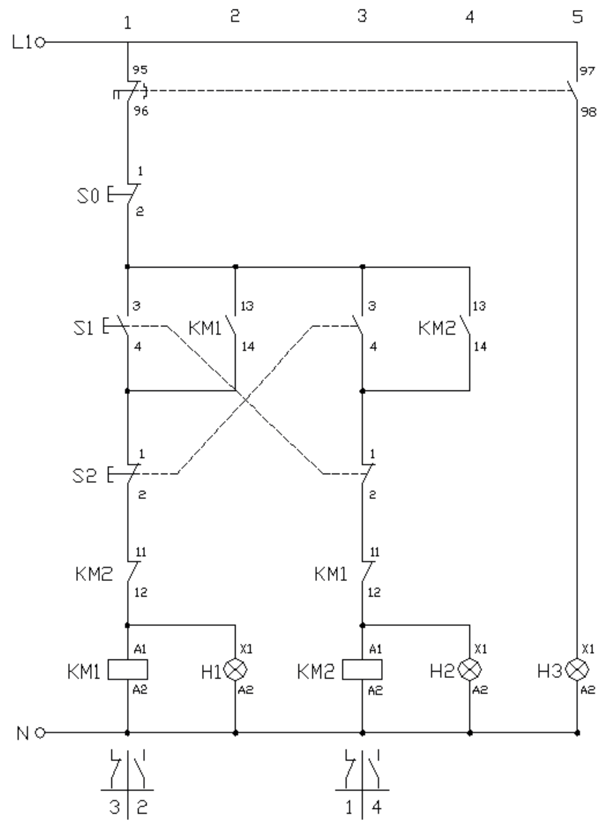

Figure 12. Control circuit.

- Screws, bolts, and anchoring elements (as appropriate according to the work panel to be used).
- One IP 55 mounting panel.
- Two three-pole contactors with one auxiliary normally open contact (NO) and one normally closed contact (NC).
- A thermal relay.
- Rubberized cable 3x12 AWG.

As the workshop is less than 15 m away, there is no need to implement protection inside the panel.

For the gear motor set the following selection was made: Gear motor with electromagnetic brake, consisting of a squirrel cage type motor and an electromagnetic brake, ideal for making an instant stop of rotation. The characteristics of the geared motor are shown in table 12.

Drum, roller and support structure. According to the calculations, weights, and stresses to which the winch was to be subjected, we designed the solution shown in Fig. 13. The layout of the final assembly is shown in Fig. 14. The final cost of the project is detailed in table 13.

As can be observed, the most representative part of the final cost of the project was the electrical part. It includes the costs of labor, tools, equipment, and material.

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Table 11

Supply, installation, and testing of electrical panel for control and force, of the electric winch.

I. Machinery and equipment				
Description		**Rate/hour [COP]**	**Performance**	**Unit value [COP]**
Electrician minor tools		$2,241	48.00	$107,580
Computer and office equipment		$833	24.00	$20,000
Truck		$15,000	18.00	$270,000
		Subtotal machinery and equipment:		**$397,580**
II. Materials				
Description	**Units**	**Price per unit [COP]**	**Quantity**	**Unit value [COP]**
Metal box IP55 1000x800x300 mm	Unit	$955,830	1.00	$955,830
Switch 18 A, 1NA+1NC 220 V T.M.	Unit	$180,315	2.00	$360,630
Thermal relay 9-14 A	Unit	$80,849	1.00	$80,849
Emergency pushbutton	Unit	$45,648	1.00	$45,648
Terminals, labels and ties	Unit	$1,218	10.00	$12,180
Station two pushbuttons green red	Unit	$72,728	1.00	$72,728
RETIE certification of the panel	Unit	$609,000	1.00	$609,000
Rubberized cable 3x12 AWG, 600 V, THW 75C	m	$5,664	10.00	$56,640
Nylon and security tapes	Unit	$1,523	10.00	$15,230
			Subtotal materials:	**$2,208,735**
III. Workforce				
Description		**Rate/hour [COP]**	**Performance**	**Unit value [COP]**
Technologist		$15,949	80.00	$1,275,948
Technical assistant		$6,844	40.00	$273,767
			Subtotal workforce:	**$1,549,715**
			Total Direct Cost:	**$4,156,031**

Table 12

Geared motor characteristics.

Reference: 1LE2221-2BC11-4AA3-Z				
Power	**Voltage**	**Speed**	**η**	**Weight**
7.5 Hp	230 V, 60 Hz (Standard)	25 rpm	0.917	262 kg

Finally, the winch installed using a set of worm gear motor and crown is shown in Fig. 15. A video showing the system in operation can be seen on: http://youtu.be/3MGqxiDfSkg

Findings

The cost of the gallon of gasoline and diesel in the municipality of Samacá (Boyacá) for the month of January 2014 is $8.585 and $8.556 respectively. The cost of kW/h for

Table 13

Final budget result.

Activity	Units	Price per unit [COP]	Quantity	Total value [COP]
Supply, installation, and testing of electrical panel for control and force of electric winch of 7.5 Hp include connection and other elements for installation and final testing.	Unit	$4,156,031	1.00	$4,156,031
Roller installation.	Unit	$181,318	5.00	$906,590
Supply and installation of support structure and drum.	Unit	$1,298,278	1.00	$1,298,278
Supply and installation of motor reducer Siemens.	Unit	$3,069,231	1.00	$3,069,231
Supply and installation of 5/8 jute core steel cable.	m	$5,400	100.00	$540,000
			Total Direct Cost:	**$9,970,130**

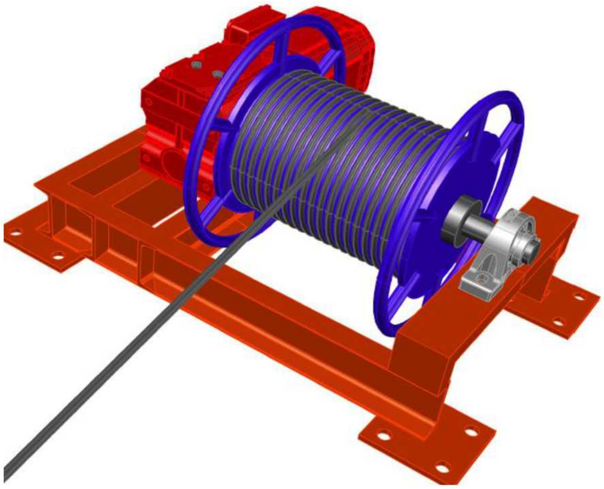

Figure 13. Solution designed for support structure and drum.

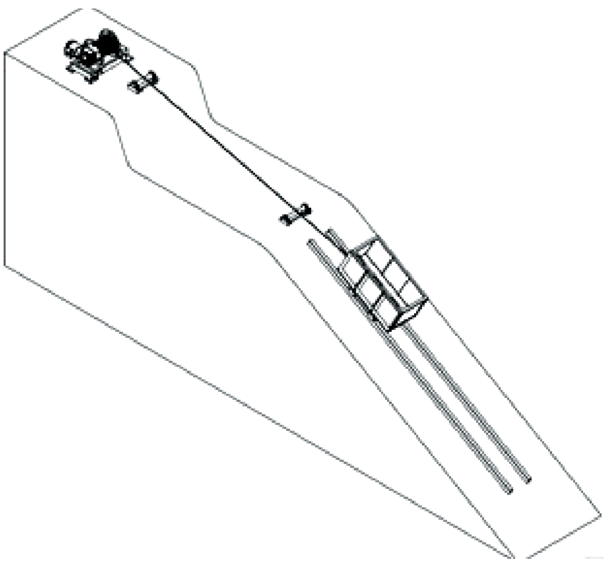

Figure 14. Final assembly.

Figure 15. Electric winch. Cochinillos mine location.

Table 14
Fuel consumption for the operation of the internal combustion winches in the Cochinillos mine.

1954 Nuffield Tractor			Dodge 1500		
Fuel consumption		Cost	Fuel consumption		Cost
22	gal/month	$ 188.936	33	gal/month	$ 284.361
5,5	gal/week	$ 47.234	8,25	gal/week	$ 71.090
0,92	gal/day	$ 7.872	1,38	gal/day	$ 11.848

Table 15
Consumption of pneumatic winch in an underground mine.

	Fuel consumption		Cost
Pneumatic winch	53,76	gal/month	$ 461.691
	13,44	gal/week	$ 115.423
	1,92	gal/day	$ 16.489

the industrial sector is $432. Taking into account an average production of 12 tons per day, we calculated the costs of the fuel used to extract the cars from the underground mine (table 14). In the case of internal combustion engines, there is a waste of fuel in the multiple turns on and off that must be made for the ascent and descent of the cars.

The use of the pneumatic winch is challenging in the mine due to the limited use of air compressors. At the time the pneumatic winch is used the other tools used connected to the air compressor must be disconnected, and yet the winch needs more air consumption than the compressor can provide (table 15). In order to avoid this inconvenience, a compressor of greater capacity is needed, which due to their high cost are not used in small mines.

The electric winch is ideal for use in these small mines (Fig. 16). The cost of preventive maintenance is low as it is limited to general cleanliness and maintaining lubricating oil levels in the mechanical elements of the reducer. Power consumption is generated only during winch operating times (table 16). The difficulties that arise in the use of this device are only due to the availability of the electrical network.

Table 16
Electric winch consumption in an underground mine.

	Energy consumption		Cost
Electric winch	246,40	kWh/month	$ 106.445
	61,60	kWh/week	$ 26.611
	8,80	kWh/day	$ 3.802

The electric winch is the one with the lowest cost of operation and maintenance. The useful life of this device is superior to that of internal combustion engines since these engines have been dismantled from the original automobiles

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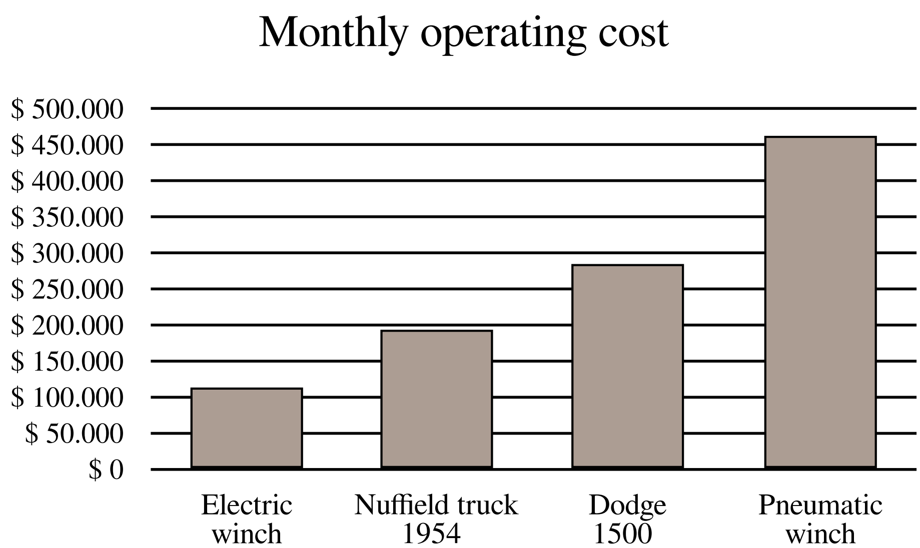

Figure 16. Monthly operating costs for different types of winches in small-scale mining operations.

and have already completed their useful operating cycle. The operating cost of the pneumatic winches is much higher than that of the electric winches and the total disposition of the air compressor is necessary for their satisfactory operation.

The operating cost of the pneumatic winches is much higher than that of the electric winches and the total disposition of the air compressor is required for their satisfactory operation.

Conclusions

In this paper, we detail the design, construction, and operation of an electric winch in a coal mine in the municipality of Samacá, Boyacá (Colombia). For its development, aspects related to the mine were considered, such as its size, type of operation and functional needs. The system also had safety, operational, financial and maintenance criteria.

When implementing the reducer motor control, in addition to performing it under standard and optimizing costs, it was sought to be a simple control, with simple parts to replace since those who operate and maintain the equipment are the same employees of the mine.

Observing the operation of the winch and compared to the internal combustion engine, it is observed that one of the advantages that the first has over the second is that it is maintenance-free but not inspection-free, and another is that energy supplies should not be made that endanger the personnel who perform it (manual fuel supply).

In the calculation of the motor, although it must be approximated to those actually offered by the market, the operation achieved for the winch was optimal. This is guaranteed according to the design and the full load tests carried out, in which the extraction time was very close to the one calculated.

The electric winch is the one with the lowest cost of operation and maintenance. The useful life of this device is higher than that of the internal combustion engines since they have completed their useful cycle of operation.

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Scale anthropomorphic hand based on human anatomy with linear actuators as the basis for motion

Mano antropomorfa a escala basada en anatomía humana con actuadores lineales como base para movimiento

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This article presents the development of an anthropomorphic hand, based on human anatomy. This prototype has a total of 20 degrees of freedom, four for each finger. The design took into account the anatomical features of the human hand such as tendons and joints for different movements. The movements are generated with servomotors and controlled directly from a computer with the help of an Arduino Mega. The parts were designed in Autodesk Inventor and printed on a 3D printer.

Keywords: Fingers, joint, linear actuators, mechanical design, prototype, robotic hand

Éste artículo presenta el desarrollo de una mano antropomorfa, basada en la anatomía humana. Este prototipo tiene un total de 20 grados de libertad, cuatro por cada dedo. El diseño tuvo en cuenta características anatómicas de la mano humana como tendones y articulaciones para los diferentes movimientos. Los movimientos son generados con servomotores y controlados directamente desde una computadora con la ayuda de un Arduino Mega. Las piezas se diseñaron en Autodesk Inventor y se imprimieron en una impresora 3D.

Palabras clave: Actuadores lineales, articulación, dedos, diseño mecánico, mano robótica, prototipo

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Introduction

The man currently lives in a box, built according to our characteristics, both psychological and physiological being his way of walking, his posture, and his hands, the three main features that are sought to imitate in anthropomorphic robotics (Martínez, Martínez, & Jacinto, 2014). In order for the technological world to continue advancing, technological creations must be truly efficient and must adapt to our daily lives. The creations need to look more and more like us.

The idea of creating mechanical anthropomorphic limbs was originally intended for prosthetics, but this concept now extends to modern robotics, which is at the height of development. With more and more humanized robot designs, it is hard to believe that these artificial systems are limited to the medical field. We live in a world by man and for man, the logical thing is that technology evolves in the direction of ourselves, either to imitate us or to adapt to us.

For example, each time a new model of cell phone or computer comes out, its ergonomic design stands out, being these our hands, the fundamental pillar in the technological development and means for the creation of infinity of possibilities because there is not being alive on the planet that can carry out tasks with its hands as the human does, and it is a fact that our evolution has been based on them. Human evolution has been based on its creativity. At first to survive and now to adapt the environment to us. Hands were the means to develop our creativity, to be able to create from lances in antiquity, to rifles today.

At the beginning of the Christian era, the hands were already replaced by different artificers. The first artificial hand, attached to the forearm, was found in an Egyptian mummy 2000 years before Christ (Dorador, Ríos, Flores, & Juárez, 2004). At the beginning of the Christian era, the hands were already replaced by different artificers. The first artificial hand, attached to the forearm, was found in an Egyptian mummy 2000 years before Christ. In the second Punic war (218-201 BC) the Roman general Marcus Sergius lost his right hand and ordered to build a metal one (Zuo & Olson, 2014).

In 1501, Gotz Von Berlichingen ordered an articulated iron hand to be built to hold his sword. However, the sword was very heavy and had to be attached to the armor. The fingers and wrist of this hand could be flexed and extended passively (Orr, James, & Bahrani, 1982).

The first mobile, but passively, an elbow-level artificial arm was built by a locksmith on behalf of the French military doctor Ambroise Paré. The fingers of the prosthesis could be opened or closed by pressing or traction. It was also Ambroise Paré who built the first aesthetic leather hand (Thurston, 2007).

In 1917, F. F. Simpson founded the *American Limb Makers Association*, in which all the manufacturers of the sector existing at that time in the United States joined. The materials used in the construction of the prosthesis began from then on to be lighter, ductile and appeared among others the aluminum alloys, the synthetic fibers, and the plastics. After the First World War, all the countries united in a common effort aimed at the best rehabilitation of the invalid. The hands designed then were interchangeable according to the different occupations (Zuo & Olson, 2014)

In the designs studied we can notice how they emphasize the grip of the objects rather than the shape of the grip. As a result, bi-directional opening and closing movements (forward and return) are obtained, in addition to using a greater force than should be used for the grip.

For several years there have been studies of the hands, we have tried to replicate many of their characteristics. For example, in (Wang, Fan, & Liu, 2012), the study is carried out analyzing the anatomy of the thumb, since it is the part of the hand that presents the greatest degree of freedom. This project proposes that in order to design the target of the hand it is necessary to start from the thumb since its rotations are complex.

The movements of the hand are too complex to design and implement in robotics, making their movements very tense (Tan, Zhang, Chen, & Du, 2009), which shows that each movement has a great effort and to verify this, there is a series of graphs where tests are made both flexibility and effort that has to obtain a grip on objects, it can be noticed the rigidity it has when making the different movements.

The term Robot, which comes from the Czech word robotic meaning *forced labor*, was first introduced by the Czech dramatist and author Karel Capek in his 1921 theatre play R.U.R (Rossum Universal Robots) (Christoforou & Muller, 2016).

Both prostheses and robotic hands have tried to achieve a more functional hand, focusing on the most common movements, however, despite all the advances of today most designs are still characterized by rigid movements and do not include the full range of possible combinations of a real hand, and those prototypes that approach real hands tend to be expensive, and therefore of limited access for people. As a result of this a less robust prototype was made, focused on performing as many movements as possible integrating the abduction and adduction movements, in addition to taking into account anatomical characteristics of the human hand and being developed with easily accessible materials.

In order to achieve the objective, it was necessary to design three previous prototypes, each with a different approach. The first one was based on a double articulation system which offered greater flexibility, but the pieces were thin and fragile as it consequently obstructs the path of the tendon inside the piece. The second prototype is similar to the first, but since its fineness of movement was not the one we wanted to obtain, it was a null design. The third prototype was designed with articulations in the shape of a

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sphere achieving greater movement, but for the assembly, it required additional safety pieces, because they were very small.

The development was made throughout 11 months, considering research, designs, selection of elements, consultation of suitable materials for the assembly, tests, and delays among others. The project had a cost of $1'600.000 Colombian pesos M/Cte, in this value is reflected only the materials used, it does not consider labor. The approximate cost for manufacturing the prototype is $750,000 Colombian pesos M/Cte (materials only).

Problem formulation

We want the hand to be seen as a means, not as an end, for this, we thought of innovative design, an effective prototype, economical, expendable and that can be adapted to the purposes and utilities of many people (Martínez, Acero, & Castiblanco, 2014).

To carry out this project, an anthropomorphic robotic hand prototype was designed and implemented with improvement in design and performance to previous prototypes of the ARMOS research group, adding the abduction and adduction movements. It was designed as a research and development platform for different hand movements, although it is only a prototype to improve with time, to give it practical use in the future and greater versatility, either as a control platform, prosthesis or as part of an advanced robot (Fig. 1).

Figure 1. Electrically active hand prosthesis in the form of a clamp or hook.

The purpose of the research project is the development of a robotic hand, whose design will focus on the reproduction of most of its movements. In order to do this, we looked directly at the source, that is to say, we tried to imitate the anatomy of the human hand or at least its motor part. Since the designs of robotic hands seen in articles and conferences consulted are focused to fulfill specific tasks, from their idea to their conception, in other words, they are focused to an end, it was decided to develop a prototype with the capacity to adapt to different circumstances. Many designs do not have the form of a hand, they are limited to put a glove with the form of one, but below this, they are a clamp, in addition, several designs are based on a system of three fingers.

Guided by the anatomy of the human hand, it is evident that many of the movements we can make with our hands are omitted, because their usability is underestimated. This is the case of the adductor and abductor movements, which are evidently omitted in the designs consulted, being these movements those that allow us to accommodate our hands for more efficient use.

Methodology and design

After defining the main characteristics that the design of the prototype of the anthropomorphic hand will have, a series of consultations begins, both in human anatomy and in articles and designs of prototypes already developed, as well as making a slight documentation on mechanical behavior, materials and software handling (Martínez, Rendón, & Guevara, 2016).

Anatomy

Hand anatomy research focused on the locomotor system, skeleton or bones, muscles, tendons, and joints (Staff, 1988).

Bones. The bones are light but very strong and hard, have very varied forms that depend on the function they perform in the body, some of these functions are:

- The protection of soft or vital organs such as the brain and the entire thoracic cavity (Staff, 1988).
- Supports most organs (Staff, 1988).
- Allow movement thanks to the synchronized contractions of tendons that are attached to the bones (Staff, 1988).

Although bones have other functions apart from those mentioned above, these tasks are more metabolic and therefore do not fall within our competence for the development of this project.

The bones of the hand are divided into three groups (Staff, 1988): Carpus, metacarpus, and fingers. The bones of the carpus are eight arranged in two rows of four bones. They constitute the skeleton of the wrist.

- Trapezium.
- Trapezoid.
- Hamate.
- Capitate.
- Pisiform.
- Triquetrum.
- Lunate.
- Scaphoid

The bones of the metacarpus are five, and they are arranged in a fan. They constitute the skeleton of the palm of the hand (Staff, 1988).

The bones of the fingers are called phalanx, they are organized in a number of three for each finger, except in the thumb that has only two (distal and proximal) (Staff, 1988).

- Distal phalanges.
- Middle phalanges.
- Proximal phalanges (Fig. 2).

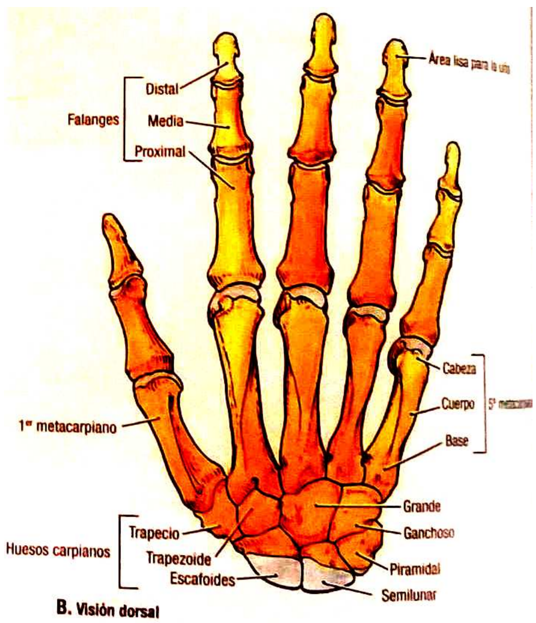

Figure 2. Bone structure of the hand (Staff, 1988).

Bone is a firm, hard and resistant tissue, it is composed of hard and soft tissues. The main hard tissue is bone tissue, a specialized type of connective tissue made up of cells called osteocytes and calcified extracellular components. Bones have a superficial covering of fibrous connective tissue called periosteum and their articular surfaces are covered by cartilaginous connective tissue. The soft components include the myeloid connective tissues hematopoietic and adipose tissue in a few words fat to the bone marrow. The bone also has vessels and nerves that respectively irrigate and innervate its structure (Fratzl & Varga, 2017).

The ligaments are masses of connective tissue in which the collagen fibers are very reinforced extends from bone to bone, these give stability to the hand.

Tendons. The bundles of muscle fibers continue with the tendon fiber, which, at the other end, penetrates into the interior of the periosteum. They are the unions of the muscles to the bones, which are not made directly, but through bands of connective tissue that constitute the tendons.

The bones are linked by the joints (Fratzl & Varga, 2017), which are classified as follows:

- Synarthrosis (immobile): When there is intimate contact between the bones, there is no joint cavity and movement is impossible.
- Amphiarthrosis (semi-mobile): Allows very limited movements, that of the vertebrae, for example, the union is made by cartilage fiber.
- Diarthrosis (mobile): The bones are separated by a joint cavity, a series of ligaments prevent them from deviating from their relationship positions. The joint cavity is covered by the synovial membrane and a liquid fills the cavity and lubricates the surfaces in contact.

Joints. The types of joints we can find are:

- Saddle joint, such as the thumb, allows movement in two directions (Fig. 4).
- Hinge joint, allows movement in one direction, such as the elbow (Fig. 5).
- Spheroidal joint, very flexible, it makes possible rotations and lateral inclinations (Fig. 6).
- Rigid joints are limited to their movement by ligaments but can support loads ().

Outline. Colombia is at the height of development in terms of prosthetics and anthropomorphic robotics, however, until some time ago there was very little research and development (Quinayas, 2010). After the arrival of the 3D printer, there was this sudden interest in designing anthropomorphic prostheses, so it is less expensive, more practical and simple to design. After carrying out complete research with respect to the anatomy, such as its movements and degrees of freedom, especially of the thumb due to its complexity of movements, it goes on to talk about different materials, structures and designs of biomechanical hands, all this in search of a natural robotic hand.

Some interesting thumb designs assume that the movement is developed by the horizontal movement of the base of the thumb, with an additional design similar to the other fingers (Mahmoud, Ueno, & Tatsumi, 2011). In these cases, there is a mechanism in which in the most important joints are located the actuators, in a mechanical system which causes the circular movement to be converted to linear by means of a mechanical coupling similar to the rack pinion. With this type of design many movements are lost and clearly in certain tasks shows a behavior less suitable for certain applications, such as typing on a keyboard or holding things.

The aim of the design is that its movements will be natural. One option to make them lighter is the use of pneumatic valves, with which a strong grip is achieved (Gaiser et al., 2008). This gives two key aspects, such as the strength and speed of the piece, but still omits many natural movements. With the pneumatic actuators, it is achieved that their movements are not so rigid, in spite of this it is achieved that it makes two movements: opening and closing, since to implement it in the design would be necessary a too robust design and would not make circular or curved movements in a natural way, this would make it deviate from the main objective, which is quantity and quality of movements.

There are also designs in which the actuators are not located in the joints, nor inside the hand, but the system of actuators are located in a separate section and from there the hand moves by means of threads and gears

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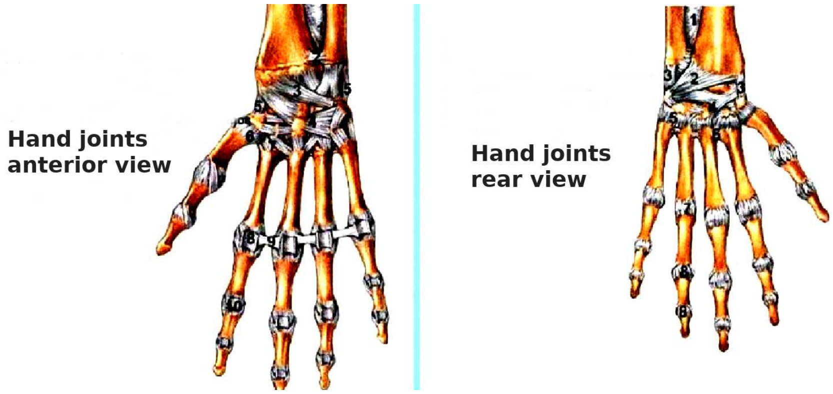

Figure 3. View of bone articulation of the hand in its two positions (Fratzl & Varga, 2017).

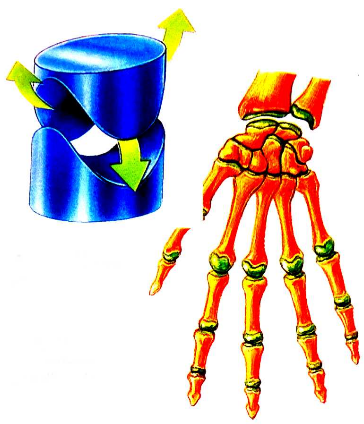

Figure 4. Saddle joint giving movement in two directions (Fratzl & Varga, 2017).

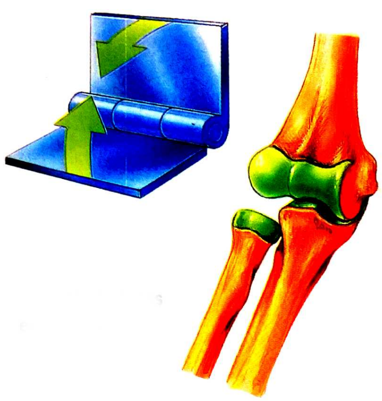

Figure 5. Hinge joint, allows movement in one direction (Fratzl & Varga, 2017).

(Niola, Rossi, Savino, & Troncone, 2014). This design shows an advantage in comparison with the previous ones because the actuators are out of the hand, it will have less weight.

As part of the sensor system, it is necessary to have a system that allows the collection of

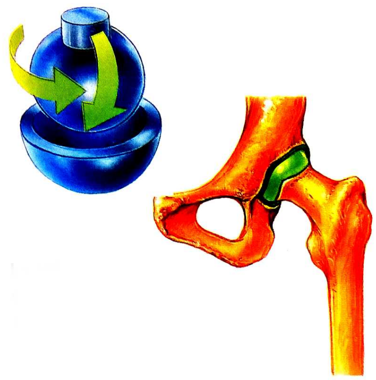

Figure 6. Spheroidal joint or rotation and lateral inclination (Fratzl & Varga, 2017).

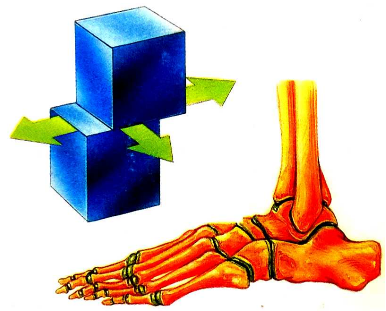

Figure 7. Rigid joint to support loads (Fratzl & Varga, 2017).

information on objects in the hand during the gripping processes (Dang, Weisz, & Allen, 2011; Zhang, Fan, Zhao, Jiang, & Liu, 2014).

Design

What is offered with this project is a change of perspective, it is not wanted an end as in previous cases, it is wanted a means. A prototype that is not designed for something in particular, but that adapts to the infinite possibilities, being our best reference our own hands and considering us mainly the movements of abduction and adduction that are evidently omitted. Being these movements, those that give us agility, flexibility and a better grip.

These capabilities can be seen in:

- To write quickly on the keyboard of the computer, since we do not have the necessity to move the whole hand, but we only move the fingers, which gives us a greater speed.
- In the case of gripping or holding objects, thanks to these movements are achieved to adopt the shape of the hand obtaining a greater firmness and variety with which it is possible to hold objects that are much larger.

Today there are many machines that make great efforts and carry out tasks that are physically impossible for a person, but there is no machine that is designed to carry out everyday tasks in a natural way. We do not propose that the prototype presented below will do all the tasks mentioned above, but this prototype shows a window into these ignored possibilities.

Hand pieces. The designed hand has 17 fundamental pieces and four additional pieces that will serve as a base. In addition, if the arm is to be implemented in the future, there will be no need to modify the hand directly, but an adjustment of the base pieces will suffice.

The parts were designed to come in under pressure because they wanted to have the least number of parts needed. Consequently, it was necessary to make certain finishes in order for the pieces to fit without the risk of fracture.

Each finger has three pieces with the exception of the thumb which has four to reach the palm, in addition to this, it is worth mentioning that the hand was designed so that it could be both right and left (Figs. 8, 9, 10, 11 and 12).

The tips of the fingers make the times of distal phalanges, this one has two holes by which the threads of hemp will go, besides that to the height of the nails the entrance to a rectangular cavity was left to annex a piece of thread-rubber that helps with the retrocession of the piece, avoiding that this one decouples. The piece in the lower part has two circular holes on the sides, these will vary their dimensions depending on the finger and will be the ones that will be coupled with the next piece and allow movement (Figs. 13 and 14).

The piece that makes the times of the middle phalanx, like the previous ones have two holes to let pass the tendons that go in the tip of the fingers, since this one serves as means for the route of the tendon, because on the one hand few people have the facility to move the tips of the fingers without moving the middle phalanx and on the other side the reduction of costs. Like the previous pieces, a protuberance was left with a rectangular cavity to annex the rubber thread, this piece has two protuberances to the sides of circular shape that fit with the holes of the pieces (Figs. 15, 16 and 17).

The pieces that will be explained next will act as proximal phalanx, these in the upper part will be coupled to the middle phalanges and therefore have two holes on the sides to make the hinge movement, in the lower part these pieces have the shape of a toroid with an opening to be coupled with the rings of the palm or in the case of the thumb with the ring that connects the finger with the palm.

These pieces have six holes, two destined to be the conductor of the tendons of the tip, two will be destined to the movements adductor - abductor and two will be to move the knuckles; according to how these pieces are coupled to the palm the hand can be both right and left.

These parameters apply to all fingers, except for the thumb, in which case the thumb moves the base of the finger up and down (Figs. 18, 19, 20 and 21).

Before reaching the palm we will talk about the piece that joins the thumb to the palm. This has a toroid shape and on one side has a cylinder with a hole, allowing the union to the palm. This piece allows the horizontal movement of the thumb and in conjunction with the adjacent piece can achieve rotary movements. It is worth mentioning that it is the only piece that does not have any type of adjustment with rubber thread and as this piece is coupled to the palm the thumb will take the form of left or right hand (Figs. 22, 23 and 24).

The palm has a toroid for each finger except the thumb in order to achieve the saddle joint, this will serve as the carpus and metacarpus except the metacarpus of the thumb.

Although the hand functions as a left hand because we wanted to keep the dimensions of a real hand we had to leave some paths that favor more the movement of the right hand.

As mentioned before, the types of bones such as carpal bones, are focused not on movement but to withstand impacts and give a little more flexibility to the hand, so that it does not suffer damage. Originally we looked for a design more similar morphologically to the human hand to achieve a better coupling to the objects, but for this, it was necessary to make the ducts smaller or the palm larger. The manufacturing capacity limited the final size of the hand (Figs. 25 and 26).

Actuator parts. For most of the movements, we use servomotors with propellers. These did not need a large displacement, with a displacement of two to three centimeters was enough to achieve the change of circular motion for a linear one. In spite of this, there are some movements that need a greater range than the propellers can offer us.

With this in mind, we designed the linear actuators, which consist of six parts: the actuator box, three conical pinions, and two racks. For the correct functioning of the actuators it was necessary to truncate the servomotors, that is to say, to achieve a 360-degree rotation instead of their normal rotation capacity of 180 degrees.

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Figure 8. Middle finger, closed, seen from different planes.

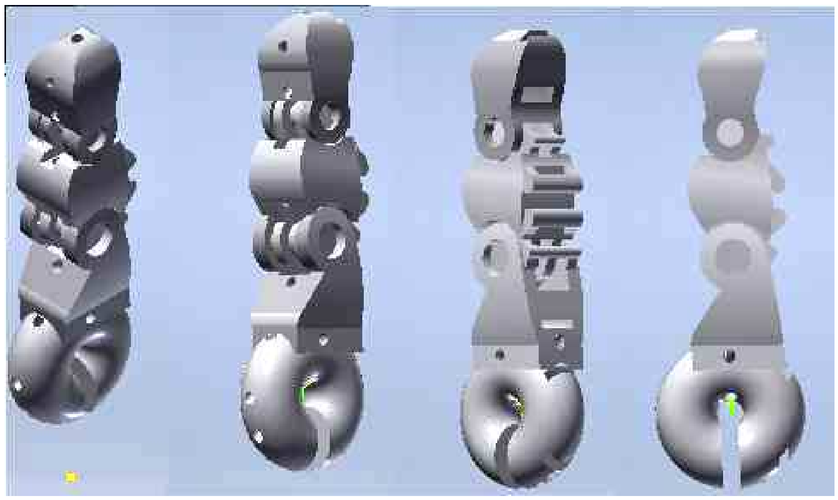

Figure 9. Middle finger, open, seen from different planes.

Figure 10. Thumb conformed in four pieces.

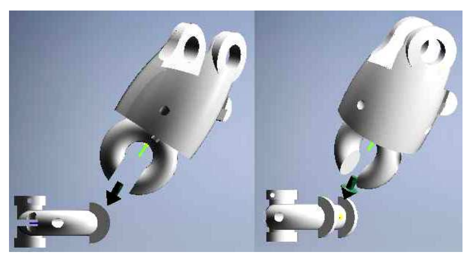

Figure 11. Union toroid and palm.

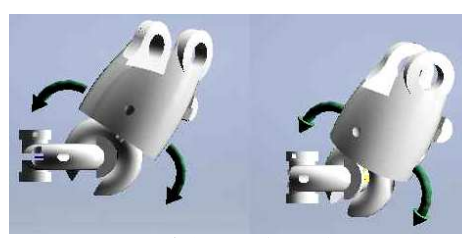

Figure 12. Movement of the toroid and palm.

The box containing all actuator parts has three sides. In the front face, there is a circular hole of approximately two centimeters in diameter that forms the pinion of the servomotor. This will be in charge of transmitting the movement to the other two pinions. To the sides we have another circular hole in each face of half a centimeter in diameter, this is used to pass a screw that is the axis of the pinions, because if they do not fit they would also come out.

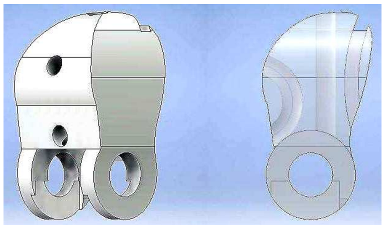

Figure 13. Fingertip and its joints.

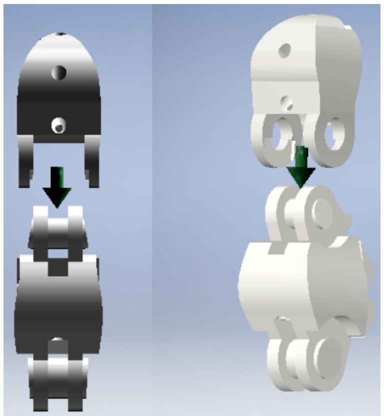

Figure 14. Connection between the distal phalanx and the middle phalanx.

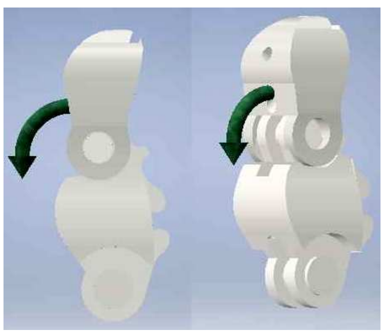

Figure 15. Movement of the joint of the phalanges.

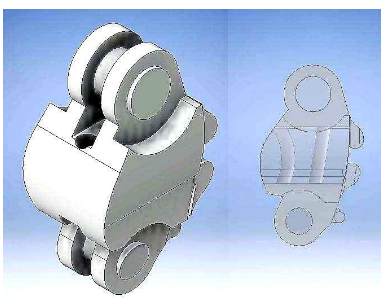

Figure 16. Middle piece or middle phalanx of the finger with its joint.

It has two vertical cavities on the sides that act as rails for the zippers (Figs. 27, 28, 29 and 30).

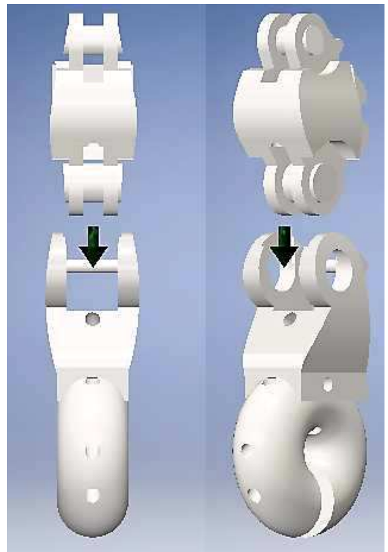

Figure 17. Connection between the middle and proximal phalanx.

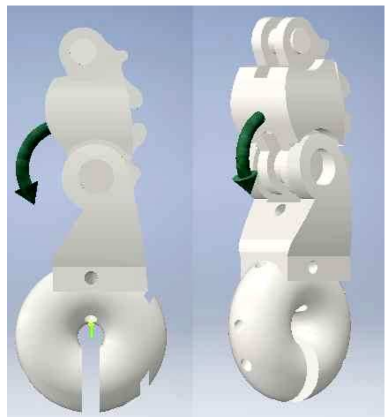

Figure 18. Movement of the joint of the middle and proximal phalanges.

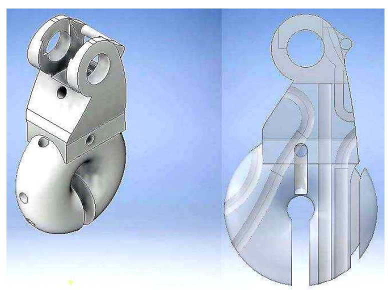

Figure 19. Union of the base of the finger to the palm with its articulation.

The first pinion will connect through the gearbox to the servo motor. This will have on each side a pinion with a circular toothed base that will be located at 90 degrees with respect to the mentioned pinion and will go in the internal

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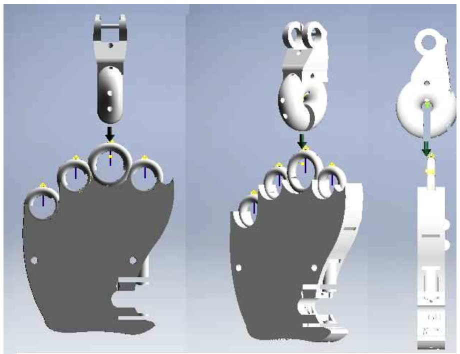

Figure 20. Phalanx union proximal to the palm.

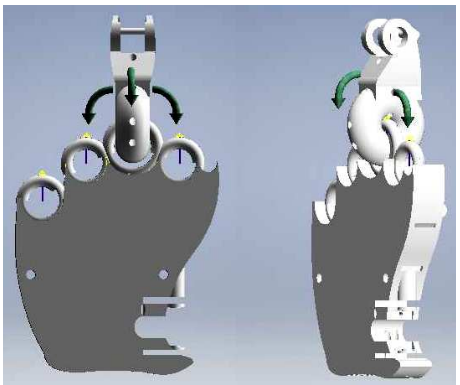

Figure 21. Movements of the proximal phalanx and palm.

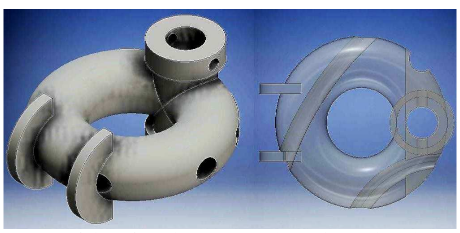

Figure 22. Toroid union between thumb and palm.

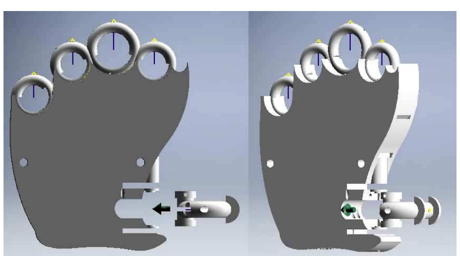

Figure 23. Toroid union between thumb and palm.

part of each face, managing to displace the zippers each one in different directions (Figs. 31, 32 and 33).

With the previous assembly, it can be seen how the movement of the motor is transmitted in two directions, exerted in the pinions on the sides, fitted to the racks that are railed in the box. In the box this set will form the actuator,

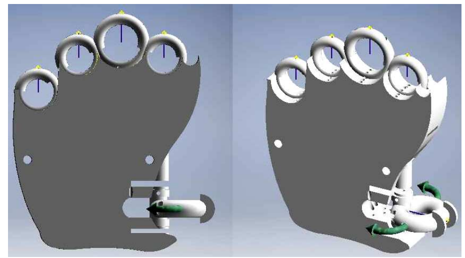

Figure 24. Movement between the toroid and the palm.

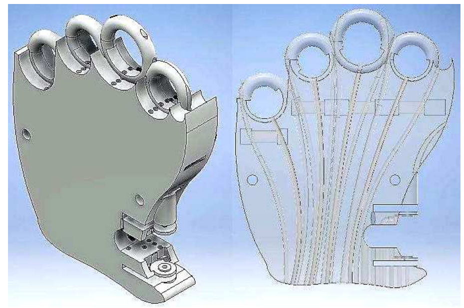

Figure 25. Palm with its joints and ring joints.

in addition, these racks must coincide with the teeth of the base of the pinions achieving a linear movement. While on one side the rack goes down, on the other it goes up and vice versa (Figs. 34 and 35).

The base of the prototype is not exactly an arm as such, it was made with characteristics similar to those of a human arm. In spite of this, not much importance was given to appearance, but the functional part of the arm was given priority over the hand, in other words in the relationship that the arm shares with the hand.

This base was made in order to give firmness and stability to the hand since it generates the movements and control. As in the anatomy of the hand, most muscles are connected to the arm, similarly the motors and actuators, which work from this position achieving each of the different movements. Otherwise, the hands would be much larger, and for the prototype, the hand would become larger and heavier. On the other side, the base or arm is also in charge of protecting the actuators and propellers from external agents that would damage their behavior (Figs. 36 and 37).

The base was made of wood for two reasons. The first, that the focus was centered on the anthropomorphic prototype of the hand, not the arm. The second, that due to its size by the actuators was impossible to print, and it was more practical to make it this way. The holes of the servo motors were made in such a way that the displacement that makes the hemp thread after leaving the printed pieces until the actuators or propellers of the servo motor should not have an angle greater than 30 degrees, because being a diagonal tension, the force is divided in two, one vertical and another horizontal. The exploitable force is the vertical

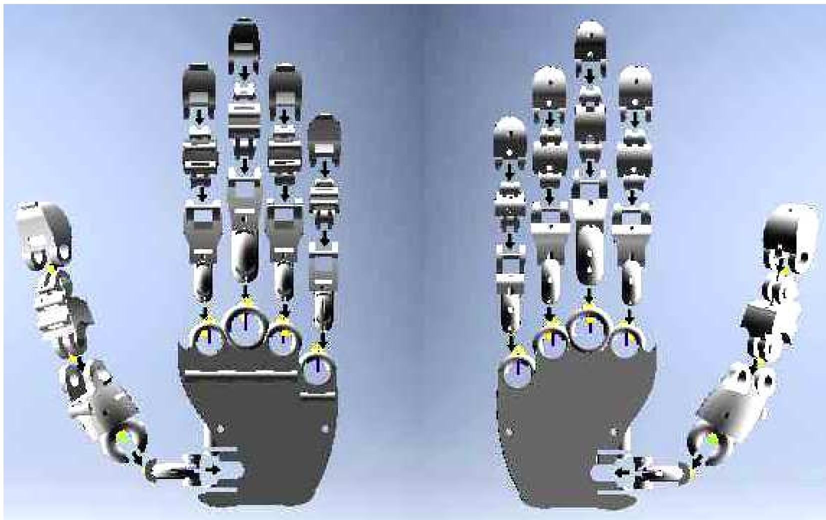

Figure 26. Right hand assembly.

Figure 27. Gear system base.

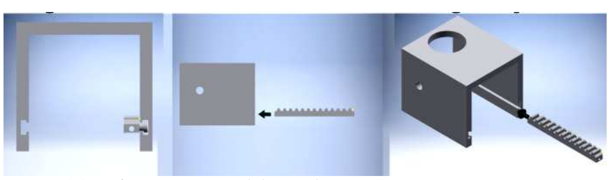

Figure 28. Zipper assembly to base.

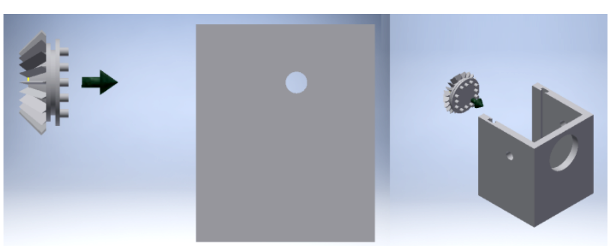

Figure 29. Main gear assembly to base.

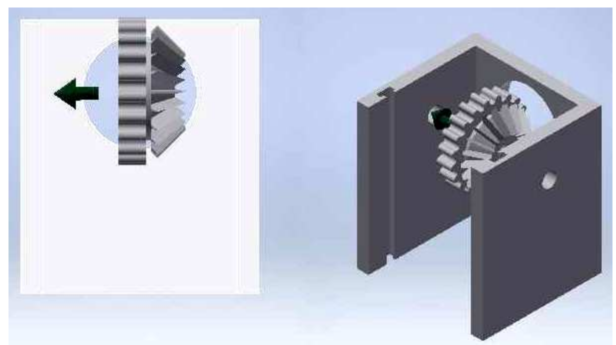

Figure 30. Side gear assembly.

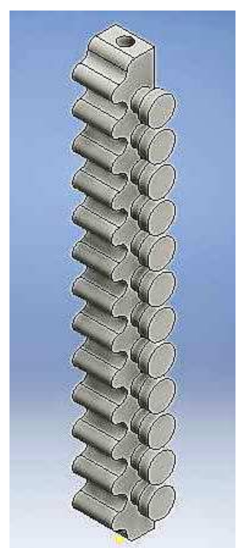

Figure 31. Track or zipper, of the movements.

one, if possible that its angle was zero, all the force of the servomotor would be exploited.

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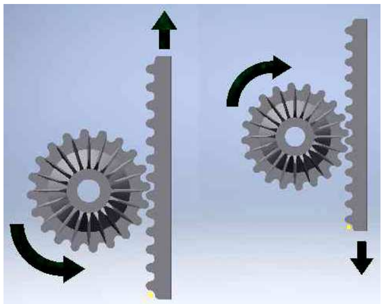

Figure 32. Change from rotary to linear motion.

Figure 33. Main gear supported to the servomotor.

Both the motors and the actuators are fitted to the base. We leave the motors on the outside to give greater stability to the motor-actuator joint. In addition, as the actuator motors were truncated, it was necessary to calibrate them with the help of potentiometers. Due to vibrations or other factors, they are sometimes unbalanced, and as the servo motor is outside, its maintenance or calibration is simple.

In order to avoid entanglements of the excess of the hemp thread, we made holes to dislodge the excess, thus avoiding other possible mechanical damages. In this way, there is no risk of the thread becoming entangled and braking any motor. This extra thread is necessary in case of replacing some propeller or zipper or simply requires to temper the thread a little more.

The control of the prototype was done directly from the computer, which will be connected to an Arduino board, and this, in turn, will be connected to power supplies, engines, and sensors.

The servo motors used are 8 Kg. Some were truncated to change their rotation from 180 degrees to 360 degrees, this due to local availability of the motors and price.

Due to the number of ports needed both to control the motors and to read the sensors, we use an Arduino Mega development board. This card has enough ports that offer the possibility of controlling many elements, giving the possibility of adding more sensors or motors, according to the future development of the prototype.

For the control, we use force sensors. These sensors were placed on the tip of each finger. Because these had several deformations, the fingers were covered with leather, protecting the sensor, and also giving a better grip, since the material itself is very smooth. The various layers of leather increased the logging range of the sensors. Sensors were also placed in the palm of the hand.

Findings

The prototype after built was not able to meet all the angles expected in their joints. This was due to the fact that in the software environment ideal conditions are handled that are difficult to fulfill in reality. By means of simulation from the design software, we define many of the degrees of freedom that the hand has. This finally exaggerated certain movements, so that the parameters of the program and adaptations were not replicated in the same way in reality. Therefore, the vertical turns that Fig. 38 contemplates in the part of the rings or toroids between the fingers and the palm, were not reproduced in the prototype.

Thanks to the material and the honeycomb form of impression, the pieces have characteristics similar to those of the bones, such as their weight and great resistance. On the other hand, there were disadvantages thanks to the printer, for example, in the beginning, we wanted to obtain more spherical pieces, despite this once printed these were deformed and corrugated at the bottom of the piece. For this reason, we opted for a more angled design, less curved, and when printing did not have many inconveniences because of its unevenness, and due to its narrow shape, these deformations did not affect the dynamics of the piece.

As with the design of the hand, when printing the pieces it was necessary to retouch and make various finishes, such as sanding the pieces so that there was not much friction with the zippers. As a result, some zippers lost their original dimensions. This caused that due to the pressure exerted by the pinion on the rack sometimes these went off the rail and it was necessary to add a wooden bar in the box, next to the racks, this in order not to allow the derailment of these.

Another drawback relates to the motor. Because the motor shaft was not completely straight, there was vibration in the box back and forth, which caused the motor to disengage from the pinion. To solve this it was necessary to attach a small golden washer to the box. To this washer is tied a rubber to reduce vibration and prevent the engine from disengaging, thus avoiding leaving it fixed, which could have produced braking, which would be reflected in an increase in current.

Another adjustment necessary at the time of construction of the actuator was to open a hole at the top of the rack and

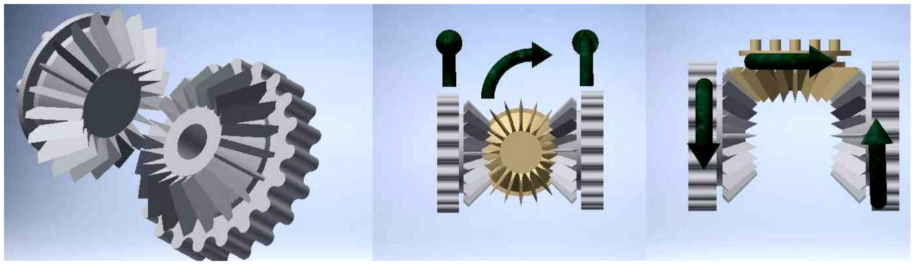

Figure 34. Change of direction of rotary motion.

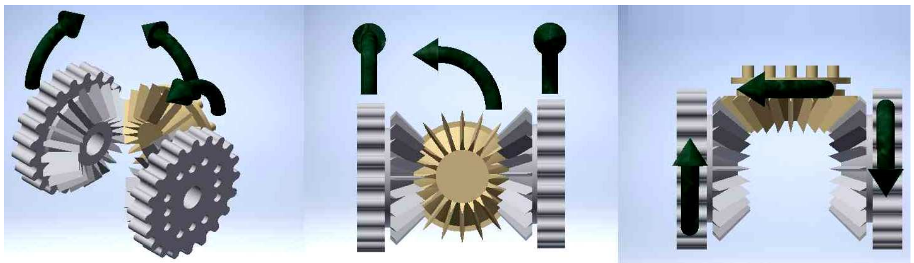

Figure 35. Turning inverter.

Figure 36. Lateral gears giving direction to the movement.

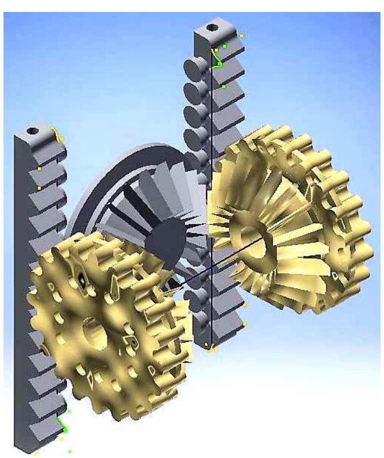

Figure 37. Lateral gears giving direction to the movement.

not through it as initially planned. These holes were mostly obstructed.

In the beginning, due to cost reasons, it was thought to generate the movement with gear motors and H-bridges. However, these motors were more delicate in the sense that when braking, the current would rise abruptly and the motor would be easily damaged. Because of this and because we found relatively comfortable servomotors, it was possible to replace the gear motors with servomotors. This change meant savings in H bridges, and easy handling, as we could operate them directly from the development board, managing to adjust both speed and displacement. In addition, the new assembly was able to withstand the overload better than the gearmotors.

Initially, the parts were intended to print on acrylonitrile butadiene styrene or ABS which is a very impact resistant plastic, also had a more convenient price compared to PLA. However, the parts were poorly resilient mechanically, and the material did not release, it was too rigid. Because of this, we opted for PLA.

It was thought to use nylon to make it act as a tendon. However, after working for a while it began to fall apart, besides that the nylon began to deform and lost the flexibility that it had in the beginning. We decided to work with hemp threads because they have good resistance to wear and do not affect the movement.

Prior to this, there were several designs, but due to their shape, these did not allow the pieces to come under pressure and ended up fractured. Consequently, it was necessary to leave between the pieces a space in the section that connects the joints, that is, the pieces have a base for the protuberance that fits with the next piece and between base and base, there

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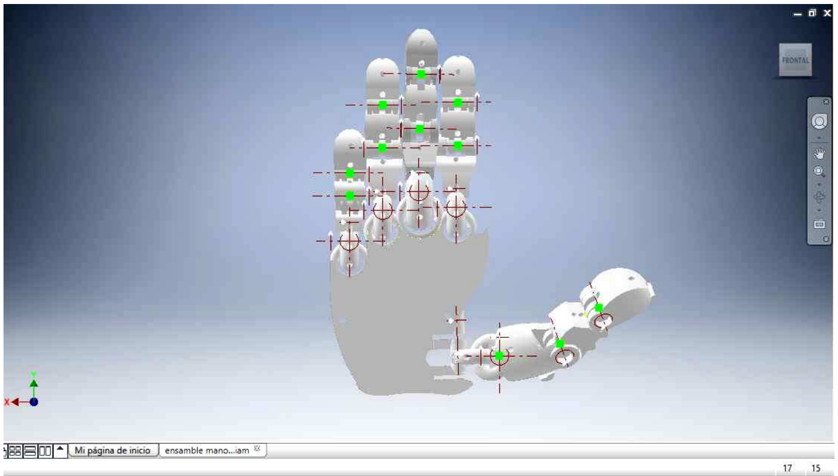

Figure 38. Simulation of hand degrees in the software.

is a space. The thickness of the base was another important aspect because if it was very thick it was not possible for it to yield and if it was very thin it would fracture. The final adjustment of the dimensions was made by trial and error.

It was also necessary to evaluate the types of joints present in the hand. In these, we found basically two of great importance: the saddle type and the hinge type. For the former, there was no need to put bumpers except for the little finger because the bumper is another continuous piece. The opening present in the pieces that are attached to the toroids of the palm was a little smaller than the thickness of these, despite this to avoid fractures the pieces were sanded so that this way there was no risk. On the other hand, for the hinged type was necessary to put stops on the back of the fingers, because without these the piece would tend to decouple and the movement would be unstable.

Another aspect that was taken into account was where the tension was generated in the pieces, that is to say, that the angle of exit of the tendon is suitable for the finger to bend, since if it is very flat it is going to need a greater force to carry out the flexion of the finger, and if it is very big it damages the aesthetics and could generate inconveniences because the thread would be more exposed (Fig. 39).

Once the hand has been assembled, we carry out functional tests with the power supplies. The measured consumption of electric starting current was 5 A. In steady state the current consumption is stabilized at 1 A.

Many of the movements are limited by the tendons, due to the limit distance that can be expected for the motors. The idea is not to exceed its point of operation, for its adjustment was opted to close the tip of the finger, then release the knuckle, and when it is bent, the knuckle is lowered. With this design and the operative adjustment of the fingers, a great variety of movements can be achieved. However, there is no direct control of the movement of each of the joints of the fingers, something similar happens with the human hand.

For the wider movements, the help of actuators was required. It was necessary to truncate some motors and change their rotary movement for a linear one since in this way the size required by the base and the movement carried out in the hand is kept under control.

Because the printed pieces differ from the digital design, they were subjected to tweaks ranging from simple filings (so that the pieces fit more smoothly without the risk of breaking the pieces) to the fact of forcing routes for the tendons. In several occasions, the original routes of the design were obstructed by the bases created in printing. In the end, many manual finishes were made to the pieces. Of particular interest was the adjustment of the parts involved with the actuators, as these require good precision because any obstruction, impurity or misplacement in the angle of operation of the part could trigger the malfunction of the actuator, in a poorly conceived movement or in the rupture of the parts of the same, in addition to risking the integrity of the motors and the development card.

For actuators, the dimensions and measurements must be precise, as their parts are small (Fig. 40). Each actuator is made up of three gears, one that is connected to the servomotor shaft part, and two at 90 degrees on each side of the servomotor shaft. Calibration is essential to get the zippers running at the same time and in the opposite direction.

To achieve the correct functioning of the linear actuator and the servo motors, these will be activated by hemp thread. This material is very resistant and will function as a tendon. Through tests with different materials, it was determined that this is the most suitable, both for its strength and for its easy travel in the actuator, from its initial position to the final position.

As already mentioned, the hand is designed to meet two characteristics: anthropomorphic scale topology, and ambidextrous handling that allows it to be used as both right

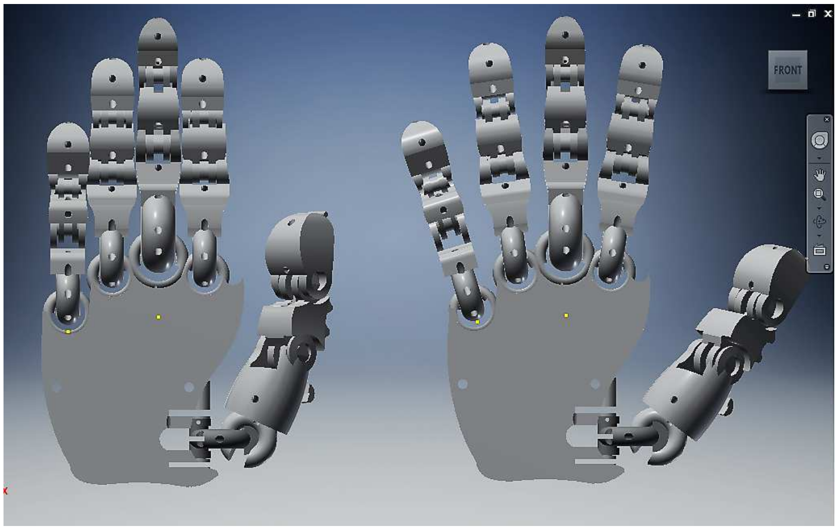

Figure 39. Final software assembly of the anthropomorphic prototype.

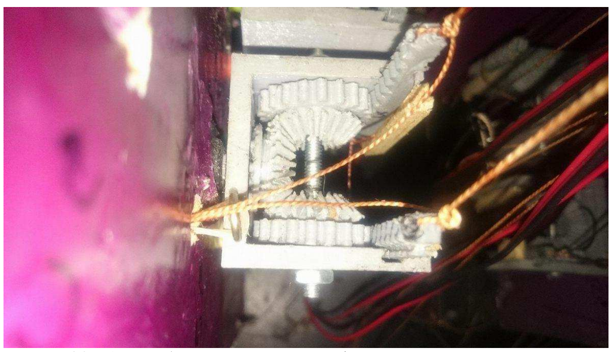

Figure 40. Actual actuator mounting.

and left hand. However, for the thumb part, it is not possible to adjust the toroid union between thumb and palm as shown in Fig. 40, but rather to adopt a new toroid or ring as shown in Figs. 41, 42, 43 and 44.

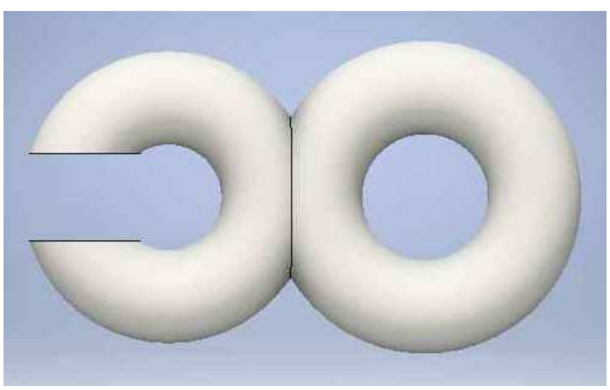

Figure 41. Reverse thumb piece.

Table 1 shows the ranges of motion in degrees measured on the prototype for each of the fingers and their joints.

Table 1

Range of motion of each finger joint.

	Tip	**Knuckle**	**Right**	**Left**
Pinky finger	60°	50°	38°	0°
Ring finger	77°	45°	40°	10°
Middle finger	40°	73°	30°	40°
Index finger	90°	40°	50°	10°
Thumb	60°	70°	0°	60°

At the tip the angle is measured from the second joint between the middle and proximal phalanx.

Conclusions

This article documents the development of an under-actuated robot hand with individual control of each finger by means of servomotors. This design took as its main basis the anatomy of the human hand, an anthropomorphic prototype, innovation, and implementation either as a prosthesis or prototype of electro-mechanized robots. Through laboratory tests, three fundamental characteristics in the movement of the actuator were evaluated: force, speed, and displacement. All with the possibility of change in different situations.

The three pinions used were designed as conical pinions of the same dimensions in order to transmit the movement without changes. In spite of this, in case of wanting to increase the force, we can play with the dimensions of the pinions. It is possible to make smaller the pinion that is connected to the motor or increase the dimensions of the side pinions, so it is possible to increase the force or do the opposite, to increase the speed of movements. In the case of displacement, if a wider range of movements is needed, what should be done is to put a longer zipper, thus covering the three needs that are required to generate the movement of the prototype.

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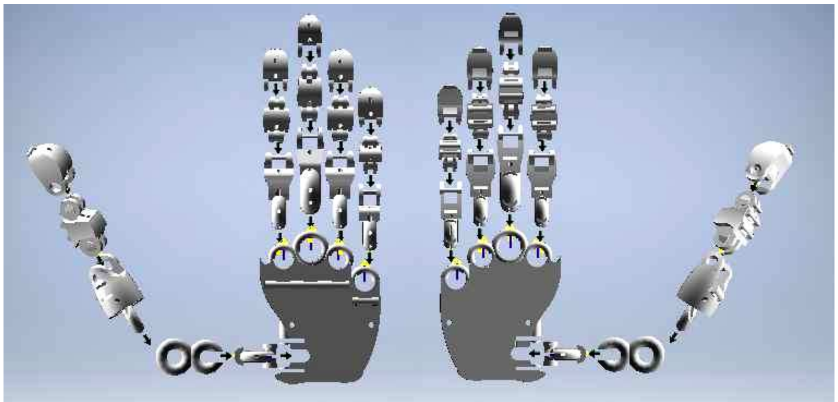

Figure 42. Left hand assembly (a).

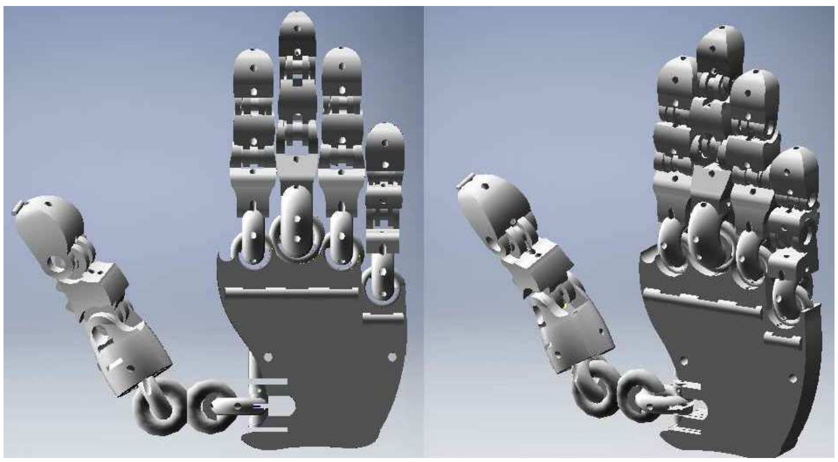

Figure 43. Left hand assembly (b).

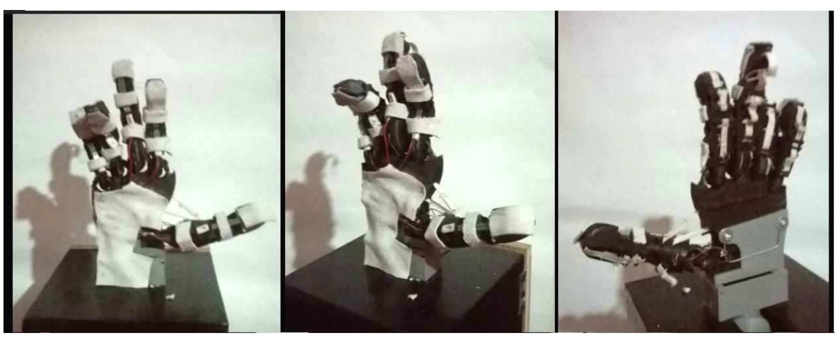

Figure 44. Anthropomorphic hand prototype based with linear actuators as a base for movement.

Since the prototype is based on human anatomy, our prototype also has some similar limitations, some more notorious than others. Among them, we have the beginning of the movement, for example, if the finger is stretched you can not bend the knuckle at 90 degrees, but is slightly raised, or the fact that the thumb to be attached to the hand is more complicated to bend its tip. However, the prototype showed a large part of the movements of a real hand. The adduction and abduction movements were achieved, in addition, the range of some movements was increased and some own movements were developed such as the inclined finger.

In the case of the thumb, in the initial design, two tendons plus one were used as a reinforcement for the horizontal movement of the base and the other to give independence to the proximal phalanx of this finger. In spite of this, when it was tried to develop it was evidenced that putting these increased their limitations and it became more complex to move this finger. Consequently, we chose to leave this one with three tendons, in this way all the fingers were left with the same amount of tendons.

It should be noted that this project shows the possibility of creating a generic hand, i.e. a hand that could be both right and left and perhaps in the future could be designed in such a way that it is not necessary to disassemble and re-assemble to make this adjustment.

On the control side the objective was fulfilled, which was to achieve an analysis of movements, that is to say, we can control each movement individually and see what possibilities we may have or on the contrary because it does not move as we had predicted.

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Study and analysis of the interaction of magnetic fields to generate unconventional mechanical movements

Estudio y análisis de la interacción de los campos magnéticos para generar movimientos mecánicos no convencionales

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This paper outlines the research on five patents related to devices employing the interaction of permanent magnets for motion generation. It also presents a physical study that exposes why the continuous operation of permanent magnet machines is not viable. In addition, simulations carried out through the COMSOL program on the patent developed by Muammer Yildiz are presented, as well as some results from Neo Teng Yi's thesis, which focuses its study on Howard Johnson's engine patent. It also shows a general analysis of the patents from a comparative table, which highlights aspects such as the way of construction, location of the magnets, among other features that are considered relevant to the understanding of the patents.

Keywords: Engine, magnetic fields, motion generation, permanent magnets

Este documento describe la investigación sobre cinco patentes relacionadas con dispositivos que emplean la interacción de imanes permanentes para la generación de movimiento. También presenta un estudio físico que expone por qué no es viable el funcionamiento continuo de las máquinas de imanes permanentes. Además, se presentan simulaciones realizadas a través del programa COMSOL sobre la patente desarrollada por Muammer Yildiz, así como algunos resultados de la tesis de Neo Teng Yi, que centra su estudio en la patente del motor de Howard Johnson. También muestra un análisis general de las patentes a partir de una tabla comparativa, en la que se destacan aspectos como la forma de construcción, la ubicación de los imanes, entre otras características que se consideran relevantes para la comprensión de las patentes.

Palabras clave: Campos magnéticos, generación de movimiento, imanes permanentes, motor

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Introduction

Permanent magnetic fields have become the object of current study due to their uses in different areas, in which it has been possible to prove certain patterns of performance and usefulness (Cao et al., 2016; Kim, Choi, Koo, Shin, & Lee, 2016; Xu et al., 2017). Some of these results, and the applications they have shown, provide a starting point for the development of this research (Espinosa, Castañeda, & Martínez, 2015).

One of the documented fields of application is the construction of magnetic motors based on the principles of magnetic attraction and repulsion (Jin et al., 2014; Liang, Pei, Chai, Bi, & Cheng, 2016). A studied example can be seen in a patent granted in 1990 (Troy, 1990), in which a motoric device is presented that in its design has a great similarity with the motors of the automobiles, since it is supported also in a block with pistons, but with the difference that to generate the movement it is not necessary the use of fossil energies, but that it uses the interaction of magnetic forces (Alonso, Gil, & Martínez, 2015).

Another similar device that has been developed, documented and patented, is a generator of electricity through a system made up of an interaction between magnetic-generator motor (Wang, 1991). Another similar patent proposed by Bedini (Bedini, 2000. Patent.) uses a similar structure, but supported by electronic circuits, allowing some degree of storage of the energy generated, which is then used in the same system.

To make these motor mechanisms more efficient, some researchers have proposed a computational method called MEC (*Magnetic Equivalent Circuits*), that operates with three DOF (degrees of freedom) (Li, Li, & Li, 2011). This system has as principle to look for the way in which the magnetic field is used more efficiently, observing that to achieve this objective it is necessary to locate the magnets in a circular configuration.

In addition to the mentioned applications, another field that has been working is the replacement of the brushes or bearings, which are a fundamental part of some kinds of electromagnetic motors (Bai et al., 2015). The change is made by permanent field magnets that are located radially and axially (Fengxiang, Jiqiang, Zhiguo, & Fengee, 2004), which allow a rotor-stator interaction to occur in such a way that they behave like a magnetic levitation system, thus reducing friction losses. This type of system generates a mechanical structure with up to five DOF (Tezuka, Kurita, & Ishikawa, 2013), and are analyzed using computational models.

On the other hand, the adoption of the use of permanent field magnets is becoming an alternative to synchronous motors. This is due to the fact that thanks to them, power, efficiency and speed can be improved, and short-circuit faults in the stator are avoided (Abdallah, Devanneaux, Faucher, Dagues, & Randria, 2004; Shin, Kim, Hong, & Choi, 2017). This allows the application of this kind of engines to be carried out for example in railways, oil excavations, etc. (Saban, Bailey, Brun, & Lopez, 2009), and electricity generation, areas in which performance is significantly improved.

A model of magnetic motor is the one designed by Howard Jonhnson, which is composed by an external rotor in which three pairs of permanent magnets with oval form are located, whose distribution is symmetrical that is obtained with a mechanical union between them. The permanent magnets of the stator maintain a distance between them that is not constant, and varies along the circumference (Johnson, 1956). Similarly, Muammer Yildiz's patent develops a machine consisting of a rotating rotor and two stators, one internal and one external. Between the two stators is the rotor and they are also made up of permanent magnets (Yildiz, 2010).

Apart from these two designs, the work carried out at the Universidad Carlos III de Madrid Escuela Politécnica Superior was also an important input for this research, where a research was carried out by Francisco Prieto de Santos, aimed at carrying out an analysis of certain proposals circulating on the Internet, which are usually referred to as free energy machines or zero point energy. One of the points dealt with in this document are the permanent magnet machines (Prieto, 2013).

Some patents on the interaction of permanent magnetic fields

It is important to clarify that there has been great interest on the part of some researchers in the construction of perfect permanent magnetic motors. However, in most of these devices, the full working models have not been achieved. To make a permanent magnet motor operate, it is necessary to perform a switching function equivalent to that achieved in electric motors by brushes, alternating current switches, or other means. In permanent magnet motors, the magnetic leakage must be shielded in order to reduce energy losses due to Foucault effects. An adequate combination of materials, geometry, and magnetic concentration are required in order to be able to build a magnetic motor that can run continuously.

Below are the results of the research of the five (5) patents selected in this research, in which it is observed that the holders of said patents take as operating principle the interaction of magnetic fields generated by permanent magnets. It should be clarified that this part of the study focused only and exclusively on what the authors of the patents expose to the reader of how their machine operates and is built.

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Muammer Yildiz permanent magnet motor

The device developed by Muammer Yildiz was assigned the patent number EP2153515 A2 on February 12, 2009, by application of the inventor. It was identified by the name of *Dispositif avec un agencement d'aimants* (Device with a disposition of magnets), in Turkey (Fig. 1) (Yildiz, 2010).

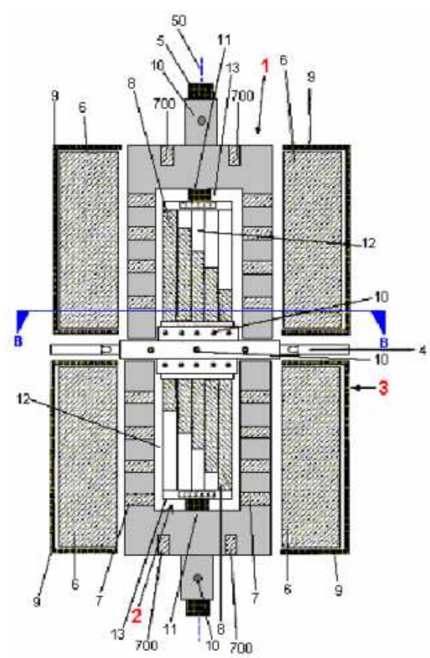

Figure 1. Motor top view (Yildiz, 2010).

The device described in the patent refers to a magnetic motor made up solely of permanent magnets located in two stators and a rotor. When mentioning the stators, it refers to the fact that the motor is made up of an internal stator and an external stator, which have a cylindrical shape and inside which is the rotor, which is also cylindrical, and to which is coupled a shaft that rotates at the same speed as the rotor. The rotor is separated from the stators by two small air spaces which in conventional motors is known as air gap.

The field produced by the interaction of the stators and the rotor is alternating and stationary as it usually happens in DC motors that do not use the so-called brushes or bearings or also in applications of systems known as magnetic levitation.

The effect produced by the stators on the rotor is of floating type, that is to say that the rotor is immersed and being affected by the fields generated by the magnets that are located in each one of the stators and that are also spaced and oriented in the system in a way that they interact with the magnets that are in the rotor. This interaction is known as an alternating field that allows the rotor to rotate in an effect that Muammer calls a magnetic bearing and which, according to him, generates few losses.

An important aspect that the inventor highlights of the device is the configuration of the stators and the rotor in terms of the location of the magnets, since for him the most appropriate way to locate the stator magnets is a rectangular or trapezoidal shape, while in the case of the rotor magnets is a circular location. Moreover, the structural shape of all the magnets, i.e. stators and rotor, are practically the same, since in this way the interaction between the fields is more efficient.

Regarding the magnetic orientation of the magnets of the two stators with the rotor, this is of repulsion, which is why it is recommended that they are located as follows: The inner stator magnets may have their North poles facing outwards and in this case, the magnets on the rotor will have their North poles facing inwards, towards the inner stator. Similarly, the outer stator magnets would then have their South poles facing inwards in order to repel the South pole of the rotor magnets, which face outwards.

Troy G. Reed permanent magnet motor

The device developed by Troy G. Reed was assigned the patent number WO1990010337 A1, on September 7, 1990, by the application of the inventor, was identified with the name of *Moteur Magnetique* (magnetic motor), in the United States of America (Fig. 2) (Troy, 1990).

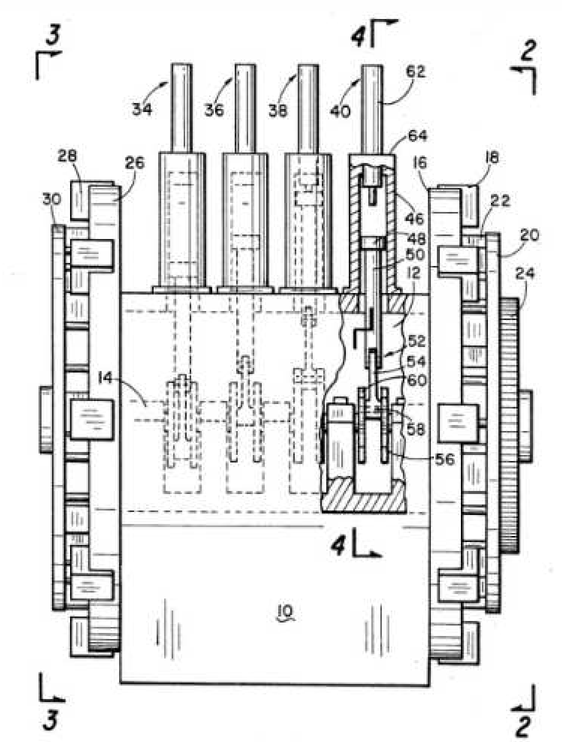

Figure 2. Motor side view (Troy, 1990).

The device described in the patent refers to a motor that converts magnetic force into rotary motion, this from the interaction of permanent magnets. The magnets are fixed around two rotating discs, so they are known as rolling magnets and distributed in such a way that they add up to eight (8), that is, sixteen (16) between the two wheels. The discs are located at both ends of a crank-shaped shaft joined together by two bearings. In addition to the magnets located on the wheels, near the discs there are another sixteen (16) fixed magnets that are distributed in such a way that they are with the same pole with which the rolling magnets were fixed, this with the objective of exerting a repulsive force between them.

The crankshaft is coupled to a system similar to that used in internal combustion engines, but with the difference that it does not operate under a principle of propulsion due to the burning of fossil fuel, but is a propulsion system caused by the interaction of fixed and rolling magnets. These have a support system that meets the objective that the movement generated operates continuously. This system fulfills the function of re-using the force exerted by a spring that is located in the injector and that is caused by a connecting rod when hitting with it, this force drives it downwards, until the crankshaft when turning returns and initiates the cycle.

The above system consists of four injection pins located at the top of the engine base. Coupled to it is the spring in charge of the rebound force. The system that hits and bounces on each of the pins is known as a connecting rod, which is inserted into an arrangement of parts similar to that found inside the retractable pens. This is attached to a pivot which in turn is attached to a crank arm and this, in turn, is attached to the crankshaft which, depending on its position, raises or lowers the connecting rod that hits and receives the force of the spring.

Victor Diduck's permanent magnet motor

To the device developed by Victor Diduck was assigned the patent identified with the number US20070296284 A1, on December 27, 2007, at the request of the inventor, was identified with the name of *Magnetic Motor*, in the United States of America (Fig. 3) (Diduck, 2007).

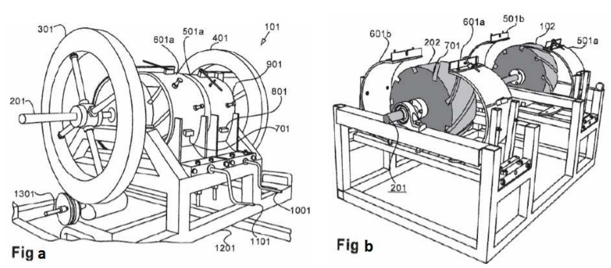

Figure 3. Parts distribution (Diduck, 2007).

The patent refers to a permanent magnet motor consisting of two rotating wheels or rotors which are attached to an axle and which the author calls *slave wheels*. A large number of slave magnets are located in these wheels and distributed along parallel grooves; each groove has a diagonal placement of approximately 35 degrees to the horizontal.

Parallel to the slave wheels, there are two non-magnetic casings with a small flow of air or between-iron that can be adjusted through two cranks located in the lower part of the engine and that are adjusted in a *threadable* way. As with slave wheels, permanent magnets are also distributed on the housings, which are located with the same polarity with which the magnets of the slave wheels were fixed. This is done with the aim of exerting a force of repulsion between the fields of the same pole, such interaction takes place in the between-iron.

As an optional part, the author places two flywheels at the ends of the motor axle, with the aim of having the option of locating a generator or other device that is responsible for converting the mechanical energy generated into electrical energy or more mechanical energy.

Howard Johnson motor

Howard Johnson's permanent magnet motor received patent approval US4151431 A on April 24, 1979, when it demonstrated the performance of its motor, which is based solely on the use of the energy contained in the permanent magnets (Fig. 4) (Johnson, 1956).

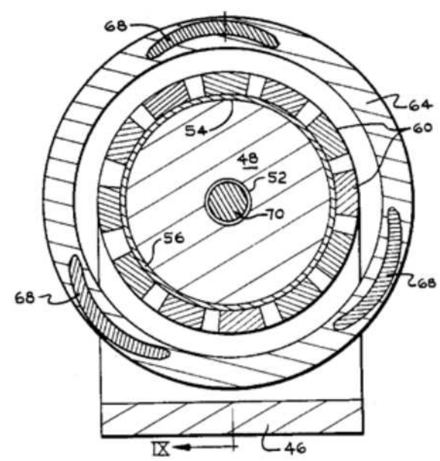

Figure 4. Motor front view (Johnson, 1956).

This device, like conventional electric motors, consists of a rotor and a stator. On the rotor side there are three pairs of stepped permanent magnets, which are connected by a non-magnetic core, the length of the armature magnets is defined by the poles of opposite polarity, but more specifically these magnets become longer than the lengths of two stator magnets plus the gap between them, the length that Howard Johnson indicates is 3.125 inches.

The stator magnets are mounted on a support plate of high magnetic permeability that helps to concentrate the force fields but the separation between them is not constant, the

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magnets of both the armature and the stator are located so that the poles of the same polarity are facing each other, this will also indicate the direction of displacement. The best gap between the armature magnet end poles and the stator magnets appears to be about 3/8 inch.

Displacement is created as the north pole of the armor passes over a magnet, which is repelled by the north pole of the stator; and there is an attraction when the north pole is passing along a space between the stator magnets. Quite the contrary, it is true with respect to the South Pole armor. It is attracted by passing over a stator magnet, repelled by passing over a space.

The interaction between the stator magnets and the armature will produce a continuous force, which will allow a displacement of the armature magnet, this is due to the ratio of the length of the armature magnet and the dimension of the stator magnets and the space between them.

A simpler way of understanding how the armature and rotor magnets interact will be described from Fig. 5 where continuous lines represent attraction forces, dashed lines represent repulsion forces, and double lines in each case indicate the most dominant forces.

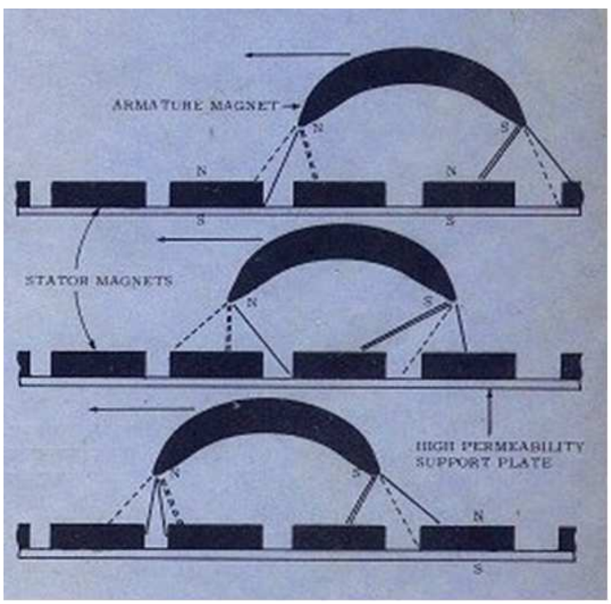

Figure 5. Diagram of assembly of magnets of the Howard Johnson motor (Johnson, 1956).

In Fig. 5 is shown that the opposing poles are north, it is observed that the displacement is directed to the left due to the interaction of forces of attraction and repulsion that occur between the magnet of the armor and adjacent magnets, more exactly in the north pole of the magnet of the armor there are three forces of attraction and two of repulsion, it should be noted that these two forces of repulsion worked against each other but it is greater that tends to move the armor to the left (double line discontinuous). This movement to the left is reinforced by the force of attraction between the north pole of the armature and the south pole of the stator at the bottom of the space between the stator magnets. Also in the southern part of the stator magnet, the same thing happens but the forces are opposite. In other words, there are two forces of attraction and one of repulsion, in whose confrontation of forces the result also tends to displace the armor to the left.

Wang Shenhe permanent magnet motor

Wang Shenhe's permanent magnet motor received patent approval CN1218329 A on June 2, 1999. A power machine based on universal gravitation that features the use of a special structure to collect energy and the use of high-intensity magnets, whose unused surface has been shielded to limit speed, which combine to generate physical movement. Its advantages are a new style, simple structure, energy saving, no pollution, smooth rotation, long service time, low noise and low-cost (Wang, 1991).

This machine consists of eight magnets evenly distributed along the surface of a metal cylindrical structure, oriented towards the inside. The outer magnets have an angle of inclination with respect to the radial direction. In the center, on a fluid that reduces friction, rotates the rotor consisting of two parts. One whose profile is a circular section that houses a fluid, and a permanent magnet. The other part has the shape of a complete disc, which contains permanent magnets again inside. The machine is completed with a cover in which the rotor shaft comes out (Prieto, 2013).

It is not easy to configure permanent magnets in a pattern that can provide a continuous force in a single direction, as there is often a point where the forces of attraction and repulsion are balanced, thus generating a position where the rotor brakes and remains stationary. There are several ways to prevent this from happening. It is possible to modify the magnetic field by diverting it by means of a soft iron component (Wang, 1991). For the side cutting of the motor in Fig. 6:

1. A cup containing a magnetic fluid used as a bearing to minimize friction. When this cup of liquid is placed in the magnetic field, the metallic powder will move, generating circular motion.
2. A four-legged device to act like an unbalanced wheel.
3. An unbalanced wheel with liquid vibration damper and a permanent magnet. The unbalanced wheel has the appearance of an automatic watch. Instead of the oscillation, it rotates. There is a permanent magnet inside, which is the main source of the Impulse Force.
4. Inner rotating shaft (rotor) with a disc containing permanent magnets. The unbalanced swivel wheel causes the inner shaft to rotate with pulses.
5. External cylinder with fixed permanent magnets (stator). External disc with permanent magnets.

6. Magnetic shielding material: used for rotation in one direction.

7. Control of on and off through magnetic field interruption using shielding material.

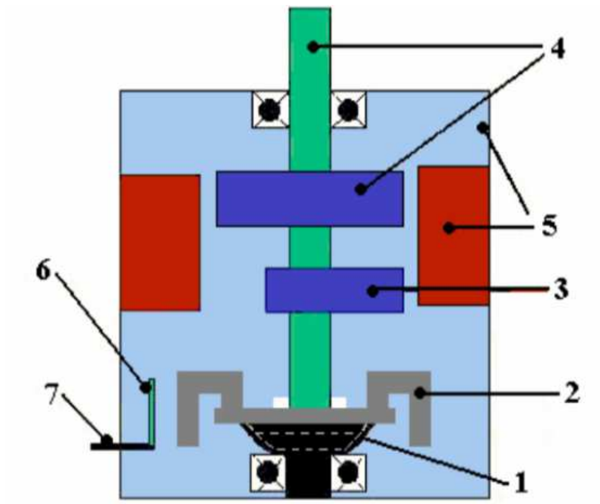

Figure 6. Motor side cut (Wang, 1991).

Analysis and observations

Considering the little information that the authors present on their patents and that they do not theoretically demonstrate the operation of these devices, which does not guarantee that these devices really work, this leads us to make a general physical study on the information that there is about permanent magnet motors. The main thing that was found was, that such devices are not possible since they would be violating the laws of thermodynamics.

To understand this we will first explain the laws of thermodynamics and also the types of perpetual motion mobiles, where the permanent magnet motors would be located. The first law of thermodynamics consists of (Eq. 1):

$$Q = \Delta U + W \tag{1}$$

The amount of energy supplied to any insulated system in the form of heat Q is equal to the work W performed by the system, plus the change in ΔU internal system energy.

The first law of thermodynamics is the application of the principle of energy conservation, which is valid for all isolated systems. The thermal efficiency e of the thermal motor is defined as (Eq. 2):

$$e = \frac{work\ performed\ during\ a\ cycle}{heat\ added\ during\ a\ cycle} = \frac{W}{Q_h} \tag{2}$$

The net amount of heat Q, which is absorbed by the substance, is the amount of heat it receives from the high-temperature heat source Q_h minus the low-temperature heat that dissipates Q_c (Tsaousis, 2008). The work produced by the gas equals the net amount of heat it absorbs (Eq. 3):

$$Q = Q_h - |Q_c| \tag{3}$$

Replacing Eq. 3 in Eq. 2 we have (Eq. 4):

$$e = \frac{Q_h - |Q_c|}{Q_h} \ o \ e = 1 - \frac{|Q_c|}{Q_h} \tag{4}$$

Efficiency can be thought of as the ratio of what you get (mechanical work) to what you pay for (energy). This result shows that a thermal machine has an efficiency of 100% ($e = 1$) only if $Q_c = 0$, i.e. if no heat is released to the cold source. In other words, a perfectly efficient thermal machine must convert all the absorbed heat energy Q_h into mechanical work.

The first law does not produce any restrictions on the types of energy conversions that can occur. In addition, it makes no distinction between work and heat. According to the first law, the internal energy of a system can be increased either by adding heat or by working on the system. But there is a very important difference between work and heat that is not evident from the first law. For example, it is possible to completely convert work into heat, but in practice, it is impossible to completely convert heat into work without modifying the surroundings. The second law of thermodynamics establishes which processes of nature can occur or not. Of all the processes allowed by the first law, only certain types of energy conversion can occur.

The second law of thermodynamics indicates that it is impossible to build a thermal machine that, operating in one cycle, has no other effect than to absorb the thermal energy from a source and perform the same amount of work.

This gives us to understand that it is impossible to build a second class perpetual motion machine, that is, a machine that could violate the second law of thermodynamics (a first-class perpetual motion machine is one that can violate the first law of thermodynamics, energy conservation, it is also impossible to build such a machine) (Inzunza, 2007).

Carnot's theorem exposes that no thermal machine operating in cycles between two given thermal focuses has a higher efficiency than a reversible machine (of Carnot) operating between the same two focuses; the Carnot Cycle consists of four processes, in which two are isothermal and the other two are adiabatic (Fig. 7) (García, Mendoza, & Camacho, 2010).

- Isothermal expansion (a-b): the gas absorbs a quantity of heat Q2 and remains at the temperature of the hot source T2.
- Adiabatic expansion (b-c): the gas is cooled without loss of heat up to the temperature of the cold source T1.
- Isothermal compression (c-d): the gas transfers the heat Q1 to the cold source, without varying the temperature.

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- Adiabatic compression (d-a): the gas is heated to the temperature of the hot source T2, closing the cycle.

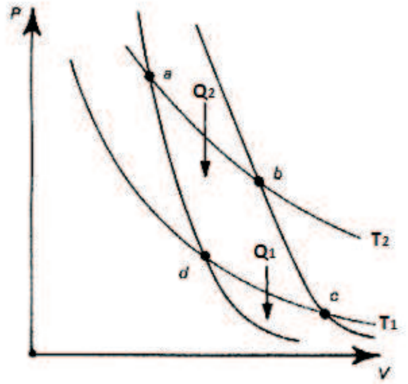

Figure 7. Carnot Cycle (García et al., 2010).

Simulation by Neo Teng Yi of Howard Jonhson's motor

Below is a part of the research carried out by Neo Teng Yi, which focused on the study of Howard Johnson's motor and other experiments that use permanent magnets to generate movement. His main tool of analysis were the simulations which were performed with the software FEMM 4.2. FEMM is known as a set of programs that can be used to solve low-frequency magnetic or electromagnetic problems in two-dimensional flat and asymmetric domains. But before performing the simulation, Neo made a schematic drawing in a 2D plane, whose design and production was carried out in Solidworks 2011. After this, he designed the model in 2D and then imported it into FEMM 4.2 for further processing and simulation. Fig. 3.32 of Neo Teng Yi's document on page 60 shows the 2D design layout of the geometry of the Howard Johnson engine model.

The design for the geometry model was defined as shown in Fig. 3.32 and 3.33 which can be seen on page 61 of Neo Teng Yi's document. The magnets that were implemented in the simulation were neodymium magnets, whose grade is NdFeB 40 MGOe. The North pole of the magnets was configured upwards and the South pole was mounted in a high permeability material that is Mu-metal type. The rotor was then designed to have a curvature shape with a sharp edge and consisted of three magnets that have 120 degrees of separation. The green direction lines indicate the direction of magnetization of the magnets in the direction pointing the arrow is the North Pole. The direction of magnetization of the curvature magnets is tangential to the rotation movement of the rotor.

After the simulation pre-processing was carried out, the problem was solved and analyzed and the simulation data were extracted from the magnetic post-processing stage. A program (Lua Scripting) was performed in order to extract the rotor torque (T) values for each 1° of rotation pitch angle. The rotor was programmed to turn left with an angle of 360° and the torque values were extracted at all pitch angles to 1°. In succession, the torque values would be used to calculate the work done (J) on the rotor for a full rotation of 360°. Fig. 3.34 on page 63 of Neo Teng Yi's paper shows the visualization of the magnetic field distribution and flux density of the Howard Johnson motor geometric model.

Simulation of magnetic unbalance forces

The constant imbalance of the magnetic force is the principle that feeds Howard Johnson's motor. The Magnetic Unbalance Forces had been simulated using FEMM 4.2 software to study and analyze the magnetic unbalance characteristics that occurred in Howard Johnson's motor. Fig. 3.35 on page 63 of Neo Teng Yi's paper shows the geometry of the 2D simulation model.

The simulation is carried out by studying the actuator which is made up of curvature magnets in three different places above the stator magnets. Fig. 3.36 on page 64 of Neo Teng Yi's paper shows the three positions of the magnets that were performed throughout this simulation. The magnetization directions of the magnets were defined as green arrows.

The rotor was programmed to complete a revolution of 360° and the rotor torque was extracted from the work performed. It was calculated and represented in a graph shown in Fig. 4.2. The comparison of torque and work performed is illustrated in Fig. 4.3 which were taken from page 76 of the Neo Ten Yi document.

Based on the graphical result, the work done has a net loss of approximately -2.3 Joules after completing a revolution, which did not reach the objective expected of the simulation. Obviously, the rotor was doing a negative job where external forces are needed to apply to the rotor in order to achieve a full rotation of 60°. Based on Fig. 4.3, the distribution of torque values is more in the negative region than the positive region. Therefore, it will result in a negative value and net loss of work performed.

The reasons that cause the net loss of work done in the simulation is probably the stator air space and the curvature of the actuator magnets, which has not been configured correctly during the simulation. Since the motor patent does not mention the exact dimensions of the motor design, the geometrical dimension of the model was designed based on a rough estimate. Therefore, it has become one of the reasons that cause the negative expectation of the simulation result. In addition to that, the configuration of the stator magnets, the air gap, and the rotor curvature magnets is very difficult to perform, which is another reason for the net loss of work.

The most important issue to obtain a continuous motor rotation is that the North Pole flow density of the rotor curvature magnets must always be lower than the South Pole flow density.

At the end of the document, Neo Teng Yi concluded that the existence of a free energy magnet motor is still an uncertain fact. He conducted a great deal of research and simulations with the aim of indicating the viability of free energy, however, the results of research did not provide firm evidence in demonstrating the movement of the motor, as they only offer some theories and basic hypotheses (Neo, 2011).

Muammer Yildiz motor simulations

For the elaboration of the simulations of Muammer Yildiz's patent, we use the COMSOL Multiphysics software which is a physical analysis program, which analyzes phenomena such as thermodynamics, electromagnetism, acoustics, among others. In the same way, it was necessary the support of the program Autocad, this one like a tool of construction of the graphical part that describes the model.

It is important to note that the simulation was performed in a two-dimensional (2D) space and we take as analysis the physical principle *Rotary Machines, magnetic part* that is part of the simulation software. It was also taken into account that the magnets of both the internal and external stators and the rotor were made of neodymium material with neodymium alloys, iron, and boron $Nd_2Fe_{14}B$, since it has a magnetic energy density of 10000 Gauss (1T) and also has a force of attraction and repulsion of ±15 [Kg] (Herrera, Alarcón, & Rivas, 2013); likewise air was used as a material in between-iron with the aim of having the model closest to that described by the inventor. We also made use of the information provided in terms of distances and number of magnets.

The results obtained were achieved from the study of stationary state in the simulator and produced the results shown in Fig. 8.

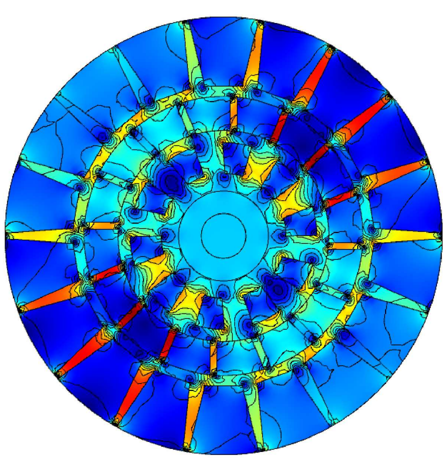

Figure 8. Magnetic field lines.

In Fig. 8 as a result of the simulation it is possible to observe the shape and direction of the magnetic field lines in both the stators and the rotor. In addition it can be observed that the lines generated by the internal stator are those that interact more with those of the rotor, whereas those of external stator do it to a great extent in the corners, which we believe that happens by the location of the magnets, since a good number are located to the sides of the blocks in the form of trapeze.

In Fig. 9 It can be seen from the speed line on the right side of the magnet graphics that the speed reached by the device in the stationary state is zero and the same in the temporal state by applying a minimum torque that can generate the human being of 5.296 [Kgf] (Barbosa & Henríquez, 2004) it was obtained that the speed reached was zero as can be seen in Fig. 10.

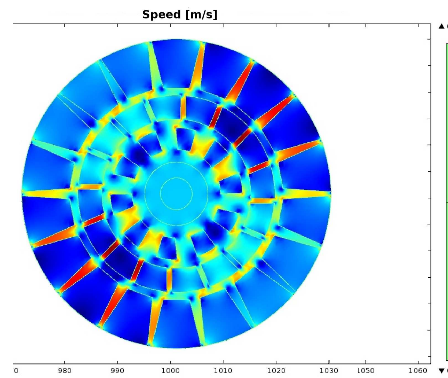

Figure 9. Speed reached in steady state.

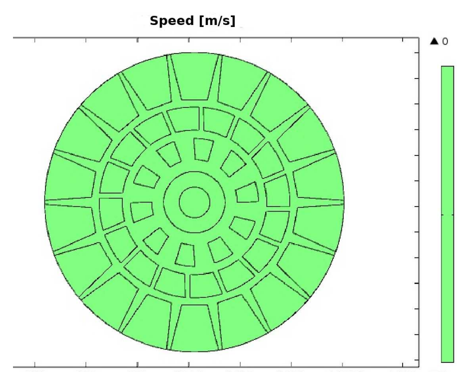

Figure 10. Speed reached in transient state.

Next in Fig. 11 is presented the graph of speed against torque in which it can be observed that in a stationary state the speed reached by the motor is zero. Subsequently, in a transient state, a torque is applied which causes the speed to increase, vary for an instant and then fall back to zero.

Similarly from the simulations can be seen how the forces exerted by the magnets on the objects that make up the motor are distributed as shown in Fig. 12.

It should be made clear that these forces do not represent the total forces exerted by the stators on the rotor, but

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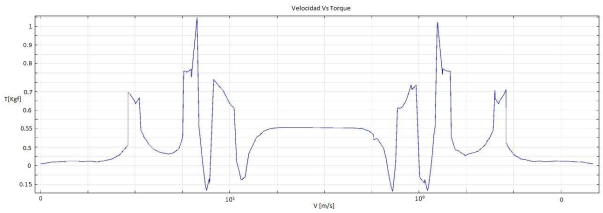

Figure 11. Variation of the speed with respect to the torque.

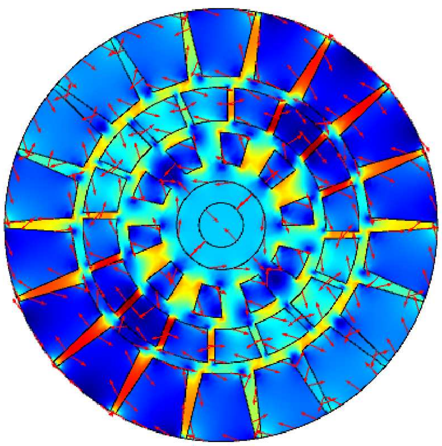

Figure 12. Speed reached in transient state.

simply represent the forces exerted by the magnets on the elements that make up the motor. From these vectors of forces represented in the image, it can be observed that the force generated by the magnets is not used in its great majority in the attainment of movement, which may be one of the reasons why the motor does not generate some kind of movement.

On the other hand, in Fig. 13 we observe the forces to which the rotor is being subjected by the stators. In the same way of this image, we observe that finally the forces are annulled, which can also be another cause that the motor does not acquire a speed.

Fig. 14 shows the vectors where the exchange of forces between stators and rotor occurs. Again, the interaction between the internal stator and the rotor, and between the external stator and the rotor can be observed.

Finally in Fig. 15 we can see how the magnetic field moves in the whole engine giving a better idea of how the interaction between each of the elements that make up the engine developed by Muammer Yildiz.

After having exposed all the development of simulation and the results obtained it is convenient to clarify that this study does not have the last word since for the elaboration of the same one did not take into account all the for minors that perhaps if it had in consideration the designer. This is due to the little physical and construction information that the author transmits to us in his patent and also because

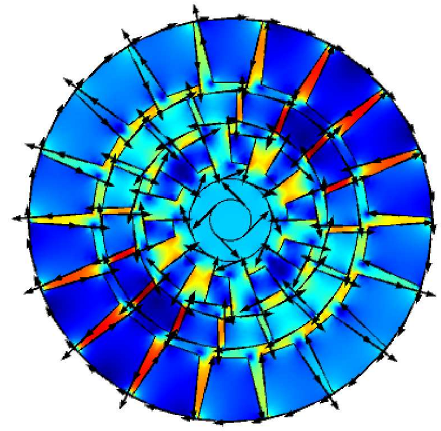

Figure 13. Stator forces on the rotor.

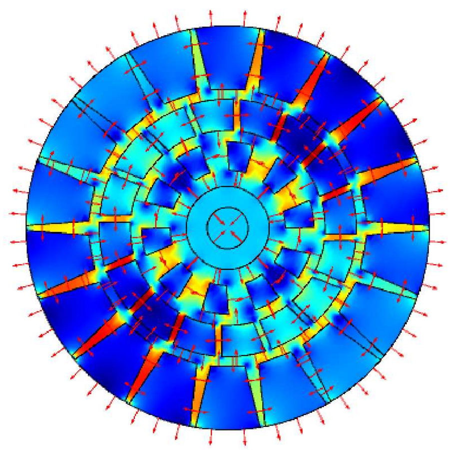

Figure 14. Lateral forces.

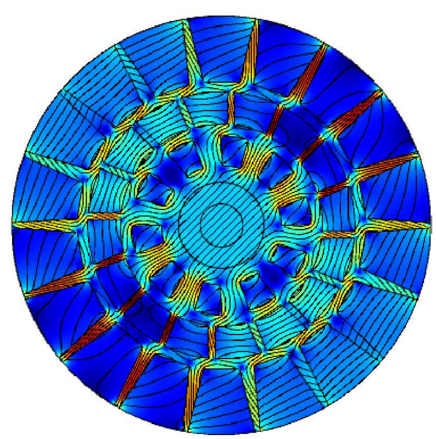

Figure 15. General field.

the physics that we know today limits us in aspects such as thermodynamics. For all this, although the results suggest that the engine can not rotate continuously if it is applying a torque, we can not rule out the possibility that the engine operates normally.

Comparative study of patents

The following is a comparative table of the patents studied, which highlights some of the characteristics that we consider to be the most important for each device (Table 1).

Conclusions

Based on the research carried out, we could deduce that by means of the physical principles of thermodynamics, permanent magnet motors that generate perpetual motion are not possible, since these can be grouped in first-class perpetual motion mobiles. In the patents analyzed, motor designs were found that use a very ingenious form of design and construction, which could be used in the research and development of electromagnetic motors that generate great reliability and efficiency. According to the simulations of Muammer Yildiz's motor, and those already documented of Howard Johnson's motor and also in different simulation programs, the same relationship was found that the motors are not functional, whether or not an initial torque is applied to them. Due to the lack of information provided in the patents and in addition to the little documentation that is found about permanent magnet motors, it is difficult for us to give an exact answer that indicates that truly magnetic motors are not functional. A patented machine or device does not always indicate that it is working correctly or that it is viable, as is the case with patents supplied to devices that involve the generation of motion from permanent magnets. Given the results obtained in both Howard Johnson's and Muammer Yildiz's engine simulations and based on these results, it would be advisable not to discard the proposed models but to try to implement them through the use of external sources. Bearing in mind that these can be very useful in some applications such as the motor of electric cars. It would be very interesting to go deeper into the investigation of the devices investigated in this document by constructing one of these mechanisms mentioned in order to have a much more general idea of the way of functioning and also to corroborate how accurate are the results of simulations.

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Table 1
Comparative table of studied patents.

Patente	Nombre y número de la Patente	Autor de la Patente	Ubicación de los imanes	Forma de construcción del motor	Aspectos a destacar	Factibilidad de Fabricación	Factibilidad de Funcionamiento
1	"Dispositivo con una Disposición de Imanes" N° EP2153515 A2	Muammer Yildiz	Se encuentran ubicados en dos estatores y un rotor, en los cuales se distribuyen de tal forma que haya una separación equidistante y la cual ejerza una fuerza repulsiva, es decir se enfrentando los polos con igual polaridad.	Esta conformado por dos estatores, uno interior y otro exterior, y en medio de ellos se ubica el rotor el cual se encuentra acoplado al eje a través de dos rodamientos de baja fricción. La forma del estator interno es de forma cilíndrica, mientras que el externo esta formado por unos bloques en forma de trapezio, y el rotor tiene la misma forma que el extator interno es decir en forma de cilindro.	Que posee dos estatores y en medio de ellos se encuentra el rotor. Es decir que el rotor esta sufriendo dos fuerzas de repulsión.	Factible pero con alta dificultad en la construcción.	Debido a que ninguna patente demuestra su funcionamiento a partir de principios físicos, y además teniendo en cuenta los resultados obtenidos en el desarrollo de este proyecto. Podemos afirmar que ninguno de estos dispositivos funciona tal como lo indican sus creadores. Lo cual nos lleva a concluir que estos dispositivos no son factibles en su funcionamiento.
2	"Motor Magnético" N° WO1990010337 A1	Troy Reed	Se encuentran ubicados en dos ruedas giratorias por lo que se les conoce como imanes giratorios. También se encuentran fijos cerca de las ruedas ejerciendo una fuerza de repulsión por la disposición de polaridades iguales.	Tiene una construcción similar a la de los motores de combustión interna, ya que el eje tiene forma de cigüeñal y a él se encuentran acoplados una serie de elementos que facilitan a los imanes el movimiento. En la parte externa se encuentran dos discos fijados a los extremos del cigueñal y en los cuales se encuentran ubicados los imanes de al interactuar con los imanes fijos generan el movimiento.	Se puede destacar que no tiene una forma de construcción convencional, ya que en la parte interna posee un eje en forma de cigüeñal al cual van acoplados una serie de mecanismos que ayudan a que el movimiento que se genera por los imanes sea de más duración.	Factible pero con una dificultad media en la construcción.	
3	"Motor Magnético" N° US20070296284 A1	Victor Diduck	Se encuentran ubicados en un rotor con ranuras de forma diagonal que rodean el total del rotor, además se ubican de forma fija en un carenado con pernos cercanos a los cuales los imanes les inducen un campo. La interacción es de repulsión debido a que tanto los imanaes del rotor y los del carenado se ubican de tal forma que las polaridades sean de igual signo.	Esta conformado por dos ruedas giratorias o esclavos, las cuales se acoplan a un eje. Paralelo a estas ruedan se ubica un carenáje ajustable a través de dos manivelas que se encargan de ajustar el espacio de aire o entrehierro. A lo largo del carenaje se ubican unos pernos enroscables que ayudan a mejorar el campo que producen los imanes en el carenaje. Como forma opcional se pueden ubicar dos ruedas en las cuales se puede acoplar un generador.	Se destaca que los imanes en el rotor están ubicados sobre ranuras que van distribuidas de forma diagonal a lo largo del rotor. Además se puede destacar que el estator es un carenaje o carcasa ajustable con el fin de aumentar o disminuir el espacio de aire o entrehierro.	Factible con poca dificultad en la construcción.	
4	"Motor de Imanes Permanentes" N° US4151431 A	Howard Johnson	Se encuentran ubicados en el rotor y estator. Los que se encuentran en el estator son de forma rectangular y la separación entre ellos es variable, a diferencia de los imanes del rotor cuya separación es la misma. Teniendo encuenta que en este solo se ubican tres pares de imanes escalonados de forma arqueada en los cuales el campo magnetico se centra en las puntas del imán, y según la polaridad de los imanes del estator sera el sentido del giro del rotor.	Cuenta con un rotor y un estator, el primero forma la parte exterior del dispositivo y sus imanes se encuentran unidos por un núcleo no magnético, mientras el segundo es el soporte y además se encuentra en el interior del dispositivo, cuyo material es de alta permeabilidad magnética. Estos se encuntran acoplados por el eje.	Los imanes del rotor son de forma arqueada, para que el campo magnetico se centre en las puntas del imán.	Factible con una dificultad media en la construcción.	
5	"El motor de Imanes Permanentes" N° CN1218329 A	Shenhe Wang	Se encuentran ubicados ocho imanes en la pared del cilindro exterior (estator) cuya separación es equidistante y los tres imanes del cilindro interior se ubican de tal manera que forman un triángulo.	En la base posee una copa la cual contiene un fluido magnético. Acoplado a este se encuentra un dispositivo de 4 patas, y estos dos a su vez van conectados al eje de rotación, en el cual se ubican los imanes del rotor y paralelo a estos pero ubicados en la armadura del dispositivos estan los imanes fijos.	Tiene una copa que contiene un fluido magnético el cual es confidencial.	No factible por confidencialidad en algunos materiales.	

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A novel design of an E-learning digital ecosystem

Un diseño novedoso de un ecosistema digital para educación virtual

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This paper shows the design of a digital ecosystem for e-learning in CONALTEL. The theoretical referents of models such as the TPACK and the Digital Ecosystem in learning are used, using them to support the construction of the proposed model and a digital ecosystem proposal for e-learning is presented that articulates seven components in the form of gears and whose function is to represent the proposed design through a dynamic system that is affected by the interaction of each component.The ecosystem model is being tested in the online learning environment http://e-ducate.co/ and in a first stage it is focusing on the exploration of the dynamics of the digital ecosystem through the pilot test of web conferences and interaction of Technologists into online learning environment.

Keywords: E-learning, learning environment, technologists

El presente artículo muestra el diseño de un ecosistema digital para educación virtual en CONALTEL. Se toman referentes teóricos de modelos como el TPACK y el Ecosistema Digital en Educación, usándolos de apoyo para la construcción del modelo propuesto y se presenta una propuesta de ecosistema digital para educación virtual que articula siete componentes en forma de engranajes y que tienen como función representar el diseño propuesto mediante un sistema dinámico que se ve afectado por la interacción de cada componente. El modelo de ecosistema está siendo probado en el entorno virtual de aprendizaje http://e-ducate.co/ y en una primera etapa se está enfocando en la exploración de la dinámica del ecosistema digital mediante la prueba piloto de conferencias virtuales y la interacción de los Tecnólogos en el ambiente virtual de aprendizaje.

Palabras clave: Ambiente de aprendizaje, educación virtual, tecnólogos

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Justification

CONALTEL has one of its mission objectives: to offer training and complementary learning that raises the scientific level of the Technologists who are subject to the inspection, monitoring and control exercised by the entity. Given that resources such as costs, time and place are limited, and in order to extend this service to the entire CONALTEL community, it is necessary to use e-learning as a strategy of coverage, relevance, access and flexibility in learning policy complementary from CONALTEL. For this reason, the proposal of digital ecosystem for e-learning of CONALTEL seeks to create a model capable of satisfying the needs of complementary learning in online modality for the Technologists that are part of the entity. Therefore, when considering e-learning and the interaction of its participants in a online learning environment as an e-learning ecosystem, it allows exploring alternatives that facilitate learning through the use of ICT information and communication technologies in an efficient manner.

Theorical Framework

The TPACK model is an emerging form of knowledge that goes beyond the three components (content, pedagogy and technology). This knowledge is different from the knowledge of a discipline or advanced technology and also from the general pedagogical knowledge shared by the teachers in the disciplines (Mishra & Koehler, 2006). It is a model that starts from good teaching practices with ICTs, using the concepts and pedagogical postulates in the use of emerging technologies, where students can solve problems and build knowledge from the integration of technologies in the teaching. (Mishra & Koehler, 2006). The design of the activities is related to the use of technologies, in TPACK it is proposed that: *"the development of the TPACK suggests the use of specific types of activities according to the contents of each discipline and enriched with technology. These activities would be like bricks that, solidly embedded, serve to construct a strategic didactic planning"* (Almenara, 2014; Baran & Uygun, 2016).

The designs of the activities proposed are:

- The choice of learning objectives.
- Making practical pedagogical decisions about the learning experience.
- The selection and sequencing of appropriate types of activities, which are combined according to the expected learning experience.
- The selection of evaluation strategies that will reveal what students are learning and how well they are doing.
- The selection of the most beneficial tools and resources for students to take advantage of the planned learning experience.

However, the TPACK model alone is not an instrument that can guarantee the relationship between the participants, the learning environment and the objectives of the institution (Herring, Koehler, & Mishra, 2016; Pamuk, Ergun, Cakir, Bayram, & Ayas, 2015). It is necessary to consider e-learning in a bigger spectrum, therefore, a trend in the way of conceiving e-learning into the digital ecosystem, (Uden, Wangsa, & Damiani, 2007) mention that a biological ecosystem is a community of organisms that interact with their environment and a digital ecosystem *"is a self-organized infrastructure that seeks to create a digital environment for network organizations that have their support in cooperation, shared knowledge, development of open and adaptive technologies and evolutionary business models"*. This relationship between a biological ecosystem and a digital ecosystem allows us to infer that individuals who participate in a digital ecosystem behave in a similar way, that is, in a digital environment; it is possible to develop adaptation and development behaviors similar to a biological environment. This approach allows us to extend the proposal of the TPACK model to involve different processes of an ecosystem in a digital learning environment, which can be transformed into a more robust and reliable model, which allows to guarantee the development of an e-learning model proposal different and with focus on interaction between individuals and the digital learning environment, as well as, a community of biological organisms and their environment.

While a digital learning ecosystem is a community that interacts individually or collaboratively synchronously or asynchronously in a digital learning environment. (Chang & Guetl, 2007) define the digital ecosystem of e-learning as the interaction between *"interest groups, learning portals, ICT infrastructure and other learning processes"*. Among the benefits of considering an e-learning digital ecosystem are: access to information, the consolidation of knowledge through the use of technological resources, the appropriation of knowledge through self-learning and learning through others, and the creation of relationships with people who are in different places and who converge in a digital learning environment (Virgili, 2013).

In this sense, (Chang & Guetl, 2007) propose an ecosystem model of e-learning characterized by three components *": (a) Content providers, (b) Consultants and (c) Infrastructure"*. Content providers offer the right content to achieve the competencies that are required of learning and using the resources available for such a case. The consultants are interdisciplinary teams that seek to structure e-learning digital ecosystem to the needs of learning, are people specialized in different areas and support different processes such as curriculum design, content design, evaluation design, design of training plans of teachers, design of planning,

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execution, evaluation and improvement of the processes of e-learning digital ecosystem. And the infrastructure is the component that deals with the technologies, resources, materials, software and other elements that give support to e-learning digital ecosystem.

Another proposed model is given by (Eswari, 2011), which shows an e-learning digital ecosystem focused on the learning environment and that interacts with six components: (a) The content of learning, (b) the management of stakeholders, (c) Roles in the environment, (d) Content repositories, (e) reports and evaluations, and (f) The process of collaboration of stakeholders. This e-learning ecosystem model focuses on the performance of the learning environment at a functional technical level and does not allow associating the interaction processes that the digital community can develop in the online learning environment.

Proposed model of e-learning digital ecosystem for CONALTEL

What should be the e-learning digital ecosystem model for CONALTEL? Every model that is implemented by an institution must meet the needs and objectives that are sought to be achieved. (Ponti & Ferrás, 2008), therefore, in this process, CONALTEL performs an organizational diagnosis and identified needs that technologists have, resulting in the proposal of an e-learning digital ecosystem model. The proposed model can be seen in Fig. 1, which has as its core the Technologists and intends that they be the central axis of e-learning digital ecosystem in CONALTEL and interact bi-directionally with the six proposed components.

The proposed e-learning digital ecosystem is considered as a dynamic ecosystem, in which each component affects the ecosystem in different degrees or levels due to its form of gears. The following explains all the components and their relationship with the ecosystem:

1. Technologists Component: It is the central component and, therefore, the most fundamental. Technologists are the ones who first activate the digital ecosystem, since the demand and training needs start from how they are performing, learning and changing over time and their work experience. Likewise, the needs that society demands of them are directed towards the other components, which, in turn, interact with each other and in some way, affect society and the Technologists, which cause an impact to e-learning digital ecosystem proposed. Therefore, it is justified that the ecosystem has a dynamic behavior or cause and effect behavior.

2. Learning Models Component: This component is made up of different learning models (Avila & Meza, 2016), pedagogy (Adell & Castañeda, 2010; Schweisfurth, 2015), didactic (Alvarez, 2012; Kozhuharova & Ivanova, 2015), curriculum (Garcia, 2010; Sledgianowski, Gomma, & Tan, 2017), instructional design (Alvarado, 2003), assessment (Bartolomé, Figueria, & Gonzáles, 2014), etc. This component has a cause and effect relationship on the other components, for example, in case of Technologists component; the learning model can impact on the development of new competencies and ways of using knowledge in the job and personal lives of Technologists. Likewise, the Technologists, having new needs, will require new learning models that can assume the generated paradigms and tendencies of society into e-learning digital ecosystem.

3. CONALTEL Component: This component contains all of processes, policies, guidelines, research and development management, strategic plans, etc., that allow the entity to guarantee the sustainability of e-learning digital ecosystem model. Its relationship with the other components is due to the fact that any change in CONALTEL component directly or indirectly impacts the other components, an example of this is the change of the institutional mission, this event can affect all the components, since could set a different policy for supplementary learning.

4. Technology Component: This component is very volatile, since technology is constantly changing (Adell & Castañeda, 2010), which, it is important to monitor their changes, since these can affect the digital ecosystem and the components of it (Hernández, Pedraza, & Martínez, 2016; Martínez, Martínez, & Montiel, 2014). An example of this is the technologies of Learning Management Systems LMS (Nicholson, 2007) they change requesting more technical requirements, the other components must adjust, both to obtain the knowledge to appropriate their management, as well as the infrastructure requirements of the ecosystem itself for its proper functioning.

5. Competences Component: This component is made up of the competences that are to be developed by the Technologists and which are articulated with the entire e-learning digital ecosystem. In this sense, for example, a competence that you want to develop is learning to learn (Calero, 2015), which seeks that the Technologist has the necessary tools to appropriate knowledge using critical thinking skills (Benton, Drage, & McShane, 2011) and self-learning (Salmerón & Gutierres, 2012).

6. Human Capital Component: This component is made up of all the administrative personnel, tutors, collaborators, researchers, senior management and people who are immersed in the e-learning digital ecosystem and who contribute to its sustainability. In the human talent component, it should be oriented to three activities: (a) Institutional / organizational activities, (b) Teaching or tutoring activities and (c) Investigation-type activities. Research plays an important role in this component, since good research practices will be able to define solutions according to the needs that the productive sector requires of the Technologists.

Figure 1. Digital ecosystem model for virtual education at CONALTEL.

7. Infrastructure Component: This component is made up of all the elements of infrastructure that the digital ecosystem requires for its support (Martínez & Giral, 2017). The relationship with the other components lies in how the infrastructure supports the ecosystem, in terms of storage, connection, software, hardware, laboratories, technological resources, LMS, among other resources (Gonzales & Garcia, 2011).

Findings

The e-learning digital ecosystem is developed for CONALTEL, which has seven components and of which six of them focus on the Technologists component. This distribution implies that Technologists are considered as a fundamental part of the digital ecosystem and that this component is the driving force of the entire digital ecosystem. The ecosystem model is being tested in the online environment `http://e-ducate.co/` and at first it is focusing on the exploration of ecosystem dynamics through a pilot test of web conferences and the interaction of Technologists in the e-learning environment, today there are more than 600 enrolled in the learning environment. On the other hand, a course in e-learning mode of professional ethics is being built, which seeks to raise awareness of the responsibility of the professional practice of the Technologist and its role into society, and another course is project management for Technologists, in order to promote development of management skills and the ability to assume responsibilities inherent to their basic training.

Conclusions

A novel e-learning digital ecosystem model is presented, in this case, applied to the needs of the CONALTEL entity. This seeks to guarantee efficiency in the proposal of complementary education in online modality addressed to Technologists who are part of the inspection, monitoring

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and control of CONALTEL. The e-learning digital ecosystem model is proposed with seven components that interact with each other in order to give a solid sustainability to the e-learning proposal that CONALTEL wishes. Pilot tests from CONALTEL into e-learning digital ecosystem are being developed through the learning environment `http://e-ducate.co/` and which is exclusively aimed at the Technologists that are part of the entity. Within future works in this proposal of e-learning digital ecosystem, is the development of adequate indicators of the efficiency of the ecosystem and the mechanisms of timely estimation of the changes that e-learning digital ecosystem requires.

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Performance evaluation of ROS on the Raspberry Pi platform as OS for small robots

Evaluación del desempeño de ROS sobre la plataforma Raspberry Pi como OS para pequeños robots

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This article presents the configuration and programming of the SERB robot for use in navigation applications, using as hardware support the Raspberry Pi Model B card, and as software the ROS OS Grovvy Galapagos. The designed robotic application uses different elements such as actuators (servomotors), sensors (proximity sensor), and an external control card (Arduino). We show the OS configuration on the platform and its performance with some basic navigation tasks.

Keywords: Path planning, ROS OS, Raspberry Pi, SERB robot

Este artículo presenta la configuración y programación del robot SERB para su uso en aplicaciones de navegación, utilizando como hardware soporte la tarjeta Raspberry Pi Modelo B, y como software el ROS OS Grovvy Galapagos. La aplicación robótica diseñada utiliza diferentes elementos como actuadores (servomotores), sensores (sensor de proximidad), y una tarjeta externa de control (Arduino). Se muestra la configuracion del OS sobre la plataforma y su desempeño con algunas tareas básicas de navegación.

Palabras clave: Planeación de rutas, ROS OS, Raspberry Pi, robot SERB

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Introduction

The present project was developed within the mobile robotics line of the ARMOS research group of the Universidad Distrital Francisco José de Caldas - Facultad Tecnológica. It corresponds to an evaluation of the feasibility of using ROS OS on the Raspberry Pi platform. This article, product of this study, specifies the different tools that were taken into account for the navigation, exploration, and displacement of the SERB Robot on a designed platform (Castiblanco & Martínez, 2014; Jacinto, Giral, & Martínez, 2016).

For the development of this application, we implemented as hardware support the Raspberry Pi card that for its low cost has become very popular in schools in England and some research centers worldwide. That is why studies have been conducted to take full advantage of the capacity of this card in various areas (Jacinto, Montiel, & Martínez, 2016).

To mention some relevant examples, we can talk about a study at the University of North Carolina, United States, in which data from the Raspberry Pi card was transmitted via Bluetooth to a touch screen. The Raspberry Pi was controlled by a modified version of the free software Debian Linux, which was optimized for ARM architectures. The screen had a graphical interface that could be controlled by users who could send data via a keyboard attached to the screen (Sundaram et al., 2013).

Another interesting case is the one of the University of Sao Paulo, where an open and low-cost code was presented for users who consume electronics. This study validated a generic *middleware* platform, to be tested on a Raspberry Pi model B card, where the results obtained show the study as an option or alternative for use as open source and low-cost (Calixto, Hira, Costa, & Deus, 2013).

A navigation system with 3-D audio systems for the visually impaired was developed at the University of New York City, USA. This consists of a special headset and microphone that are synchronized with a compass, gyroscope, and GPS system. Blind users can interact with this system, telling them the route and direction they want to go through the microphone. These commands are then processed by the Raspberry Pi card, which finally transmits to the user the correct route to follow (Jizhong, Ramdath, Iosilevish, Sigh, & Tsakas, 2013). This is a case of great interest in stand-alone navigation applications.

Also at the Institute for Real-Time Learning Systems of the University of Siegen, Germany, an architecture was designed to link the programming language BML (Programming Language used in the systematization of robots in the military field) with the operating system ROS. It was demonstrated that it was possible to execute orders by means of BML that were processed by ROS and thus be able to assign specific tasks to a group of robots (Remmersmann, Tiderko, Langerwisch, Thamke, & Ax, 2012).

The emergence of the ROS operating system made possible a new low-cost navigation and programming technique on various standard robot platforms. Thanks to this, several studies and researches have been carried out on new methods of application of the ROS operating system in a variety of devices with innovative programming languages. Some of these studies are presented below:

- In the Trinity University, United States, a study in sixteen varieties of ROS OS was carried out in order to determine the most suitable in basic tasks of robotic movements, in order to be used in future robotic investigations for the same students of the Trinity University. The results obtained showed that the best ROS OS for robotic movements or displacements was the ROS Player/Stage, which is also easy to manipulate and navigate (Kerr & Nickels, 2012). The ARMOS research group has adopted Player/Stage as a simulation platform in its research projects.
- An architecture in BML *Behavior Markup Language*, which was based on Petri networks (useful in the design of hardware and software systems, for the specification, simulation and design of various engineering problems), was carried out at the Worcester Polytechnic Institute, United States, in order to ensure that errors are not generated that may appear in the robot control systems when synchronized with the operating system ROS (Holroyd & Rich, 2012).
- At Laval University, Canada, an open source library was created for academic use that is simple and flexible for communication between ROS and Matlab. This library allows easy integration between sensors and actuators of a robot with Matlab code. This library was also designed for a quick connection between a robot being run by ROS and users who handle Matlab code (Hold-Geoffroy, Gardner, Gagne, Latulippe, & Giguere, 2013).
- The University of Wisconsin-Madison presented the programming language *Robot Behavior Toolkit*, implemented in open source as an ROS module, which focused on an analysis of the behaviors of people in the community environment, so that later this type of behaviors or expressions can be reflected and simulated, in some movements of the robots, where they especially worked on the expressions of the gaze (Chien-Ming & Mutlu, 2012).

All this research points to the versatility of both hardware and software for professional training tasks in engineering and research. There are many more documented cases, however, those cited here are considered as fundamental concepts for the development of this project.

Problem formulation

For applications in navigation of small robots with limited hardware/software resources, it is normal to use hardware platforms such as Raspberry Pi, Arduino, BeagleBoard, Mbed boards, etc. It is also common the low-level programming of these systems, which is perfect to perform tasks of medium complexity. However, when the task becomes complex, you want to evaluate many different strategies or you work with swarms of robots, the solution at this level becomes complicated.

In this sense, considering the limitations of the hardware, but at the same time the advantages provided by a development interface with ROS OS, the concerns arise, can you program an interface between the Raspberry Pi card model B and ROS OS? If there is an interface between the hardware (Raspberry Pi) and software (ROS OS), can you design a robotic application with acceptable performance? Does the robotic application between the two tools meet aspects such as the decrease in resources, the performance of the robot to perform the task (navigation), and compatibility?

Methodology

Setup of Raspberry PI platform

In the development of the robotic application in navigation, several elements were used. The first step consists of the initial configuration of the Raspberry Pi board, where an operating system compatible with Raspberry Pi is installed.

To download the operating system image an 8 Gb Micro SD is used, which will perform the ROM memory task on the board. The image that is downloaded and executed can be found at `www.raspberrypi.org`, where the NOOBS option is chosen. The main characteristic is the affinity with Archlinux, OpenELEC, Pidora, RISC OS, RaspBMC and Raspbian. To implement the operating system or image on the board it is necessary to choose the option shown in Fig. 1.

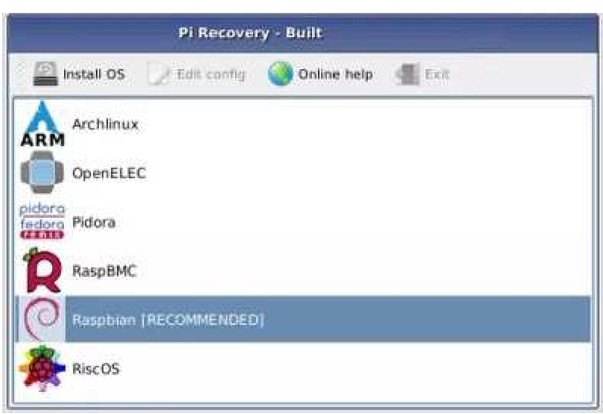

Figure 1. Image selection.

Raspbian image

The next step is to insert the memory into the Raspberry Pi, where they also connect the different peripherals that are: mouse, keyboard (which are connected by multiple USB inputs), screen that is connected through HDMI cable, where the card is powered through a cell phone charger of 5 V and 0.7 A, as shown in Fig. 2.

Figure 2. Development board connection.

Raspbian setup

Once the installation script is executed, the initial Raspbian menu will be accessed, where nine different characteristics or specifications for the correct functioning of the image on the card are observed. The menu is shown in Fig. 3.

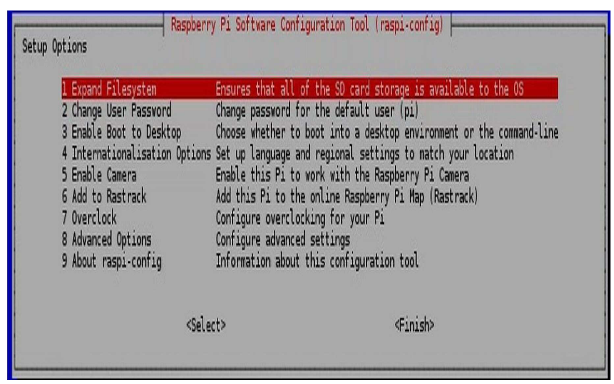

Figure 3. Configuration tool.

- The first option is to expand the memory of the Micro SD. And for the case of the running project is not necessary, because the NOOBS image is already predetermined to fully occupy the memory space.
- In the second option, it is possible to change the password to enter the system.
- The third option determines if it is required to access the graphic mode of the system or directly to the command line, in this case, it was determined to access the graphic mode which is done through the command `startx` (Xserver).

- The fourth option consists of specifying the time zone, language, and keyboard layout. I1 specifies the language, where it is recommended to select UTF-8 which corresponds to Colombia (coding that allows *ñ* and accents). Option I2 specifies the Colombia - Bogota zone, the keyboard configuration is the standard so option A3 *"PC indicates generic keyboard with 105 keys (intl)"*.
- The fifth option is to activate `Ctrl + Alt + Backspace` to close the graphics mode, where the default setting is chosen.

The above specifications are sufficient to enter the Raspbian graphics mode. The last request to enter the system is to type the username and password, codes specified below:

```
Usuario: pi
Contrasena: raspberry
startx
```

Wi-Fi connectivity

For easy control of the Raspberry Pi board, it must be connected to the Internet, and for this, there are two ways to connect it by UTP cable or Wi-Fi antenna. For the present project, the Internet configuration is done through Wi-Fi antenna. Below is a description of the necessary specifications for its configuration.

- Before starting Raspbian, the Wi-Fi antenna is connected to the Raspberry Pi board.
- When accessing the graphical interface, the Wi-Fi Config icon is accessed. The Wi-Fi device is recognized by the active USB option.
- When clicking on the scan option, whose function is to identify the different available networks (the Wi-Fi network in which the configuration is going to be made must be active or with the option visible), we verify the options and choose the appropriate network, in which the key is entered.
- The following window shows the data of USB port, Wi-Fi network and the IP address handled by our Modem or cell phone. This information is necessary for connection and control of the Raspberry Pi board remotely, as shown in Fig. 4.

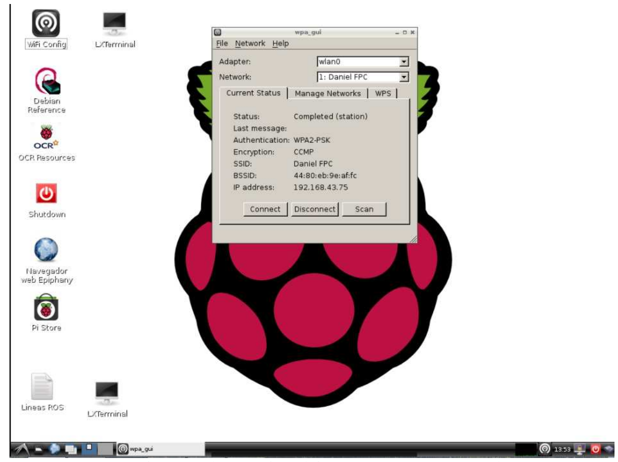

Figure 4. Configuration of Wifi on Raspberry Pi.

Remote connection using SSH

As its name indicates is the option to operate remotely the Raspberry Pi board, this means that the connection of the different peripherals are not necessary. Because the programming will be carried out by means of a computer connected to the same Wi-Fi network with which the card works, this configuration is shown below:

- The following command is entered in the terminal window:

```
sudo apt-get install ssh
```

- The service is started with the following command:

```
sudo /etc/init.d/ssh start
```

- And in order for the execution of the previous command to be carried out immediately when starting to work with the board, the following command is executed:

```
sudo update-rc.d ssh defaults
```

The following will be the installation of the SSH client in Windows, for this, you must download and install the PuTTY program that is used to enter the command terminal remotely. PuTTY is a free licensed SSH, Telnet, rlogin, and TCP raw client. The download is located in the following link `http://cplus.about.com/`, where different options are found, but due to its ease of work, the installer version is the best option. This can work in a way compatible with the Raspberry Pi board because it contains an even higher level of security for the proper management of programming.

Once downloaded and installed on Windows, you can access the Putty program to establish the connection with the Raspberry Pi board and then enter the Host Name option, where you specify the IP address to which the Raspberry Pi board is connected, Port 22 is specified, you assign a name to the connection in the Saved Sessions field and click on Saved, this way you will not have to specify the IP address and name when you start working with Raspberry Pi remotely. Thus, when the board is turned on, the previously established specifications are loaded by selecting the name of our IP and loading the option by clicking on load and clicking on open as shown in Fig. 5.

By means of the remote connection with VNC, it is possible to access the desktop or graphic mode of the board remotely. The procedure is as follows:

- Enter to the terminal window the following command, which consists of the installation of the VCN server on the Raspberry Pi board. This will load the remote desktop.

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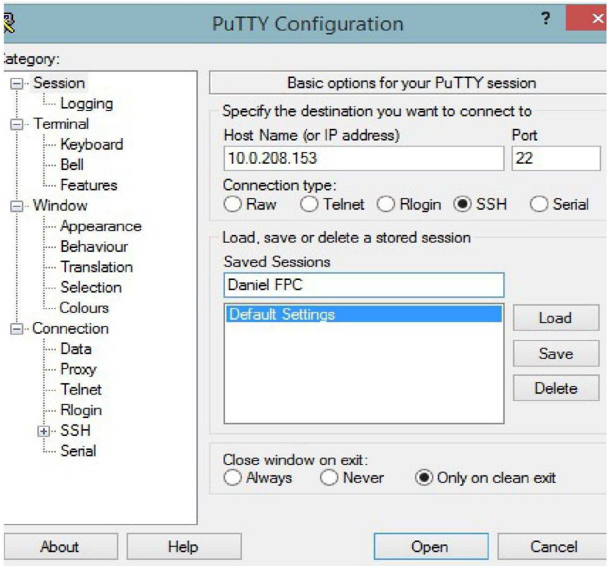

Figure 5. Putty Wifi network specifications.

This command can be executed using the PuTTY application (Fig. 6).

```
sudo apt-get install tightvncserver
```

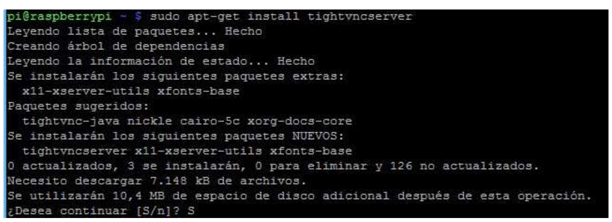

Figure 6. VNC server.

- When the installation of the VNC server is completed, the board is restarted, so that it works correctly, when it is restarted, the following command is executed:

```
vncserver :1
```

- The above command specifies different aspects of VNC, as the number 1 indicates the remote desktop we are going to use. The first time we make use of Raspberry Pi through VNC requests that a key is created (this is entered by the user, this is due to security protocols).
- The next step is the installation of VNC through Chrome, which was chosen because any programmer can make use of Google Chrome, which has the option VNC Viewer for Google Chrome, which allows access to the Raspberry Pi desktop, where it identifies that the images and colors used in the program are of very good quality adjusting to the request for the development of applications in robotics.
- In this window you enter the IP address used by the Raspberry Pi board and the desktop number used, to finally connect to the Internet as shown in Fig. 7.

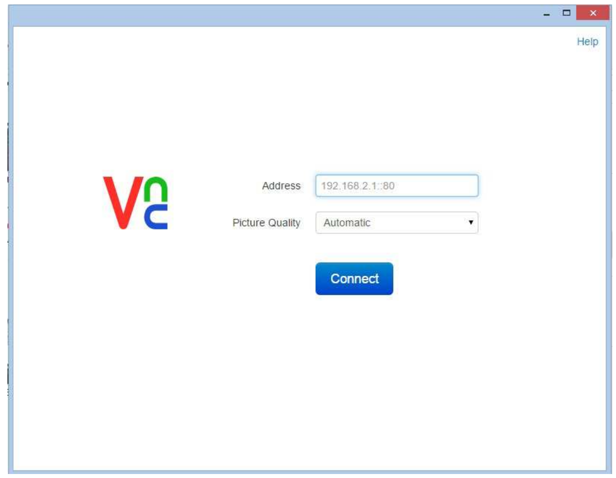

Figure 7. Google Chrome VNC Viewer Application.

- The following window can be omitted because it does not affect the configuration of the program, therefore the option not to display again is selected.
- The last step is to enter the previously created key. In this way, we enter the graphic or desktop mode of the Raspberry Pi board.

Before starting the installation of Arduino on the Raspberry Pi board, it is necessary to specify why the use of this development system. First of all is due to its microprocessor, which has the power and ease of programming for the execution of the project. Additionally, it allows the operation of servomotors (power) and sensors isolated from the control unit.

- To install Arduino correctly, update the database of Raspbian Linux packages by running the command:

```
sudo apt-get update
```

- When the upgrade is complete, proceed to install the Arduino package from the Linux server with the command shown below, where you will get the Electronic icon on the Raspbian start bar, which leads to the Arduino IDE shortcut. The Arduino installation is shown in Fig. 8.

```
sudo apt-get install arduino
```

- This step verifies that the Raspberry Pi normally detects the serial ports of Arduino, that the communication or interface between the microcontroller and the board is correct and executes the programmed application, this is done through the following command:

```
sudo usermod -a -G tty pi
```

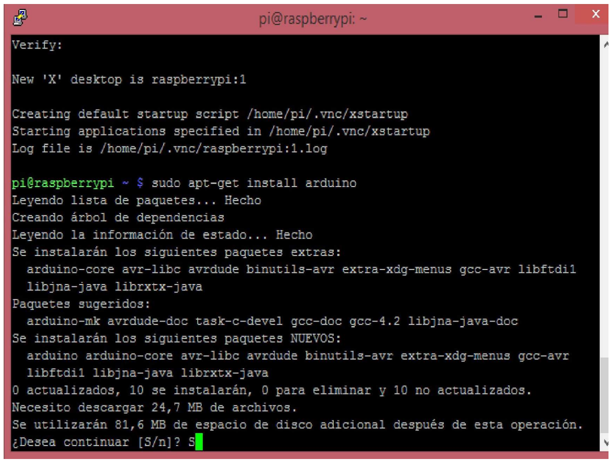

Figure 8. Updating packages.

```
sudo usermod -a -G dialout pi
```

```
ls /dev/tty*
```

Port verification is shown in Fig. 9. The image identifies that the board is working with Arduino via the `/dev/ttyACM0` port.

Figure 9. Arduino serial ports.

- It is now possible to verify the installed program by entering the Arduino IDE icon. This icon is located in the Start menu, Electronics - Arduino IDE as shown in Fig. 10.
- The next step is to configure the communication port between the Raspberry Pi board and the Arduino. This is done by accessing the tools icon, Serial Port and selecting the option `/dev/ttyACM0`. The configuration is shown in Fig. 11.
- The next configuration is to specify which type of Arduino board is available, in this case, the board is Arduino Uno, and the specification in the Raspbian system is shown in Fig. 12.

Installation of ROS OS Groovy Galapagos on Raspberry Pi

Installing ROS on the Raspbian operating system can be done in two ways (ROS.org, 2016), which are described below:

Figure 10. Location of the Arduino IDE Program.

Figure 11. Serial port configuration.

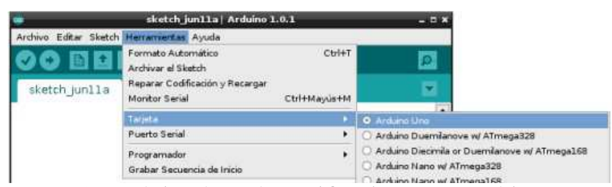

Figure 12. Arduino board specification on Raspbian.

Installation from source code. This process can take a long time to install due to the number of packages it contains. It is not recommended because the installation has compatibility problems.

Installation by binary packages. This installation method is much simpler and faster, although it lacks several packages for different applications, but has the right requirements for the development and execution of the robotic application in navigation. Its installation is done in the following way:

- ROS repositories are installed on the Raspbian system. It consists of adding the ROS OS repositories from command mode, entering a terminal and typing the following code:

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```
$ sudo sh -c 'echo\\ "deb http://packages.ros.org/ros/ubuntu wheezy main" >/ etc/apt/sources.list.d/ros-latest.list'
```

```
$ wget https://raw.githubusercontent.com/ros/rosdistro/master/ros.key -O - | sudo apt-key add -
```

• Update packages (again given the new repository entered into the system):

```
$ sudo apt-get update
```

```
$ sudo apt-get upgrade
```

• Installation of ROS OS packages:

```
$ sudo apt-get install ros-groovy-ros-comm
```

• Installation of ROSDEP. These are dependencies of the ROS OS system that the system requires to run basic ROS OS components, not installed by default:

```
$ sudo rosdep init
```

```
$ rosdep update
```

• Completion of installation. The last step is to tell Raspbian the location of ROS, the next command should be executed whenever programming is done on ROS OS:

```
$ echo "source /opt/ros/groovy/setup.bash" >> ~/.bashrc
```

```
$ . ~/.bashrc
```

• Installation of rqt plot. This tool allows visualizing numerical values in a Cartesian plane using traces of the infrared sensor reading. This application is used to verify on screen the distance at which the IR sensor is located from the different objects that are close to its path. The command is shown below:

```
$ sudo apt-get install ros-groovy-rqt
```

```
$ sudo apt-get install ros-groovy-rqt-common-plugins
```

• The second way to install this application is through the command:

```
$ rosdep install rqt_plot
```

• To start or verify the plan with the rqt plot package, enter the command:

```
$ rqt_plot
```

• Creation of the workspace. It consists of creating an exclusive workspace for ROS and the programs to be developed. This workspace is basic and essential for the non-affectation of the Raspbian system.

```
$ mkdir -p ~/catkin_ws/src
```

```
$ cd ~/catkin_ws/src
```

```
$ catkin_init_workspace
```

• In the second command, the acronym src is empty inside the folder `catkin_ws` or workspace. The workspace is opened using the command:

```
$ cd ~/catkin_ws/
```

```
$ catkin_make
```

• When the workspace creation process is finished, the `catkin_ws` folder will get two subfolders: `build` and `devel` where the relevant devel folder is because the `.sh` files or packages are stored in this folder.

• To finish with the installation, go to Raspbian with the ROS system and the new packages or workspaces by means of the following command:

```
$ source devel/setup.bash
```

This completes the installation of ROS on Raspbian and the right conditions for the development of navigation applications.

Integration between Arduino IDE and ROS OS

The procedure for installing the Arduino IDE was mentioned earlier, which specifies that the program is compatible with the Raspbian system, but lacks compatibility with ROS OS. Thus, the integration of the two systems is done through the `Rosserial` protocol or package (A., 2014). The `Rosserial` installation takes place in the `scr` subfolder of the `catkin_ws` workspace folder by executing the following commands:

```
$ cd ~/catkin_ws/src
```

```
$ git clone https://github.com/ros-drivers/rosserial.git
```

```
$ cd ~/catkin_ws
```

```
$ catkin_make
```

```
$ catkin_make install
```

```
$ source ~/catkin_ws/install/setup.bash
```

At the end of the Rosserial installation, the ROS `lib` folder is created containing the libraries for communication between Arduino and ROS.

This package must be moved to be recognized in both ROS (workspace) and the Arduino IDE. It is taken to the `sketchbook/libraries` folder, which is located in the Arduino IDE folder in Raspbian. This step is done by executing the following commands:

```
$ cd ~/sketchbook/libraries
```

```
$ rm -rf ros_lib
```

```
$ rosrun rosserial_arduino make_libraries
.py
```

Robotic platform

For the system performance evaluation, the SERB robot was selected for the execution of navigation tasks (Oomlout, 2013). It is a differential robot of design *open source* moved by two servomotors. The original design was modified in order to mount the Raspberry Pi board, distance sensors and a rechargeable battery for power supply. Taking into account the characteristics of the movement of this robot, the tasks of navigation and avoidance of obstacles are designed. The final structure of the robotic platform is composed as follows:

• Two wheels of 13 cm of diameter connected to each side of the robot in order to offer stability and independence of mobility, in addition, they are connected each one to a servomotor that is responsible for realizing the rotation in the axes for the displacement, these are fed by means of a portable battery charger that delivers 5 Vdc

• A third wheel of three cm diameter totally independent. It will not be linked to any other element, serving only to support the fixed horizontal base.

• In the horizontal plate is the different peripherals such as the Arduino Uno board, the IR GP2Y0A41SK0F infrared sensor, two portable chargers, two servomotors, a protoboard, the Raspberry Pi board, and Wi-Fi antenna, as shown in Fig. 13 and Fig. 14.

• The navigation task was designed for the robot to move independently, so the power will be supplied by two portable chargers. The first charger is feeding the two servo motors and the IR infrared sensor. The second charger will exclusively feed the Raspberry Pi board. The Arduino Uno is connected to the Raspberry Pi, so its power supply is received via the board. Fig. 15 shows the electrical connection of the first portable charger. Fig. 16 shows the electrical connection of the second portable charger.

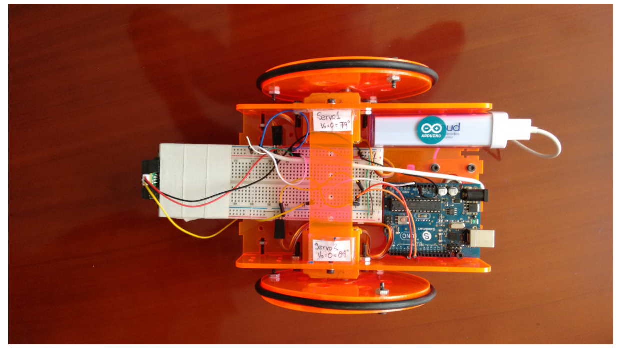

Figure 13. Platform horizontal view 1.

Robotic task

The execution of the robotic task is performed through the following procedure:

• When we turn on the Raspberry Pi board, which is connected by Wi-Fi and previously synchronized with the computer that performs the monitoring task, we access the command line to start ROS, through the code:

```
$ $ roscore
```

Fig. 17 shows the starting of ROS OS on the Raspberry Pi.

• The next step is to synchronize ROS OS with Arduino via command line in a new window or terminal. This is to locate the working space or folder. The next command is entered:

```
$ cd ~/catkin_ws/ && source devel/setup.
bash

$ cd
```

Fig. 18 shows the output that is displayed on the terminal. The communication between ROS OS and Arduino starts with the code:

```
rosrun rosserial_server serial_node _port
:=/dev/ttyACM0
```

• The control of the servomotors is carried out in a new terminal, where the task of speed and direction can be changed by means of the code:

```
$ rostopic pub servo1 std_msgs/UInt16 -
-once 180
```

The characteristics of the servomotors are specified in Fig. 19.

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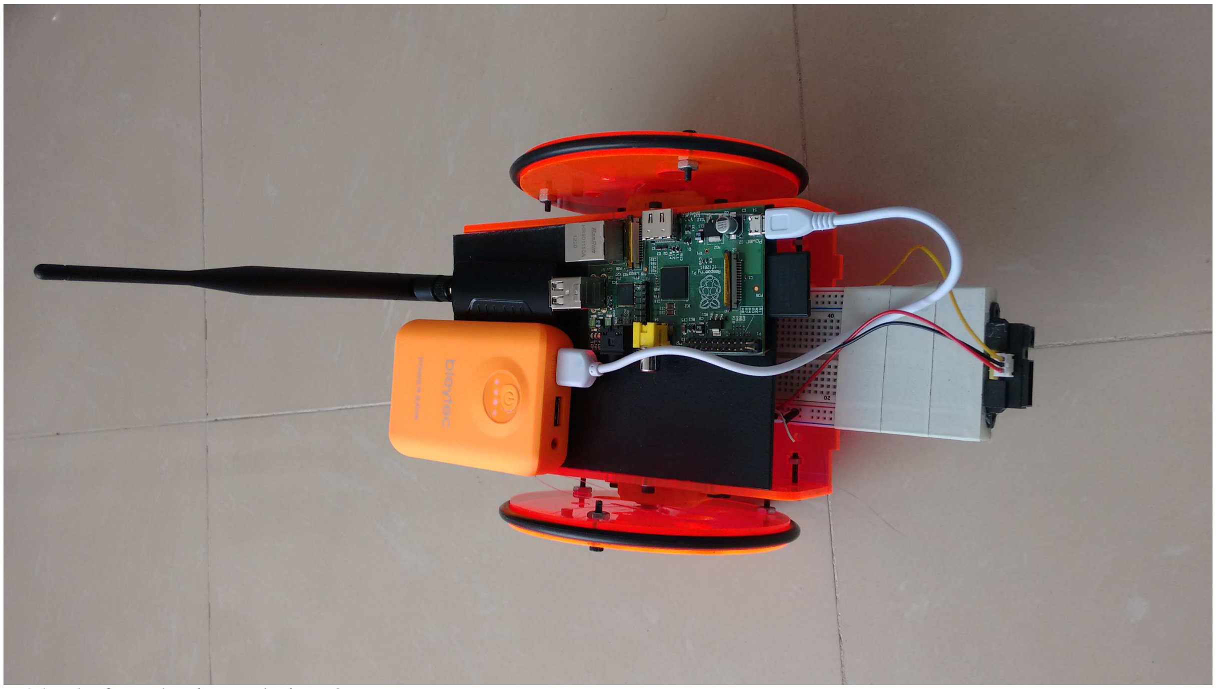

Figure 14. Platform horizontal view 2.

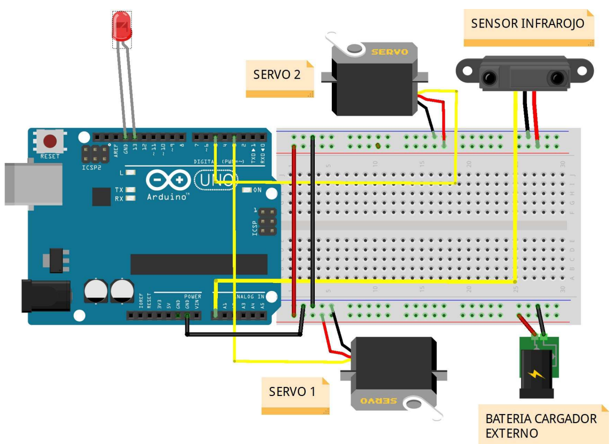

Figure 15. Electrical connection, portable charger 1.

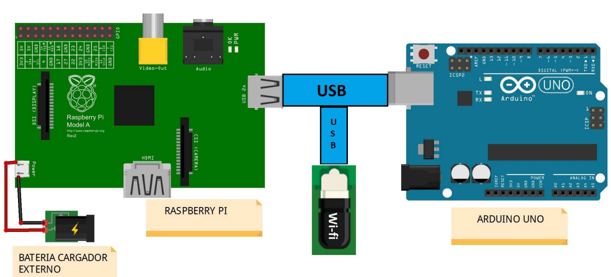

Figure 16. Electrical connection, portable charger 2.

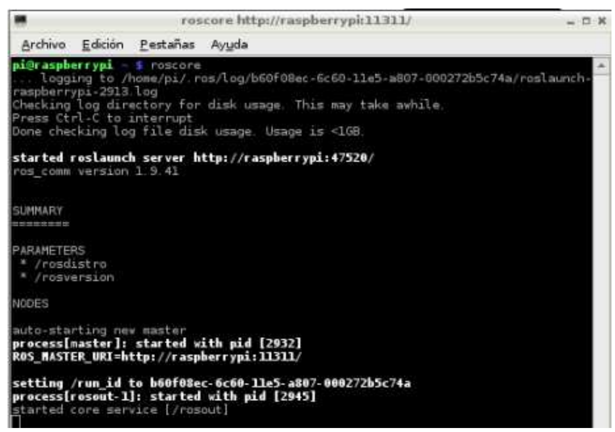

Figure 17. Beginning ROS OS on Raspberry Pi.

- The servomotor to which speed and direction are assigned is indicated, this characteristic is modified through the angle. For this case, the maximum speed and direction of advance are assigned with an angle of 180 degrees. This speed can also be reached with an angle of 0 degrees but will be displaced in reverse. When the angle is equal to 90 degrees the speed of the servomotors is zero.

The above command shows control over the servo motor called servo1. The control of the two servomotors (servo1 and servo2) is done by means of a terminal, and the command to be entered is:

```
$ rostopic pub servo1 std_msgs/UInt16 ––
once 180 && rostopic pub servo2 std_msgs/
UInt16 ––once 0
```

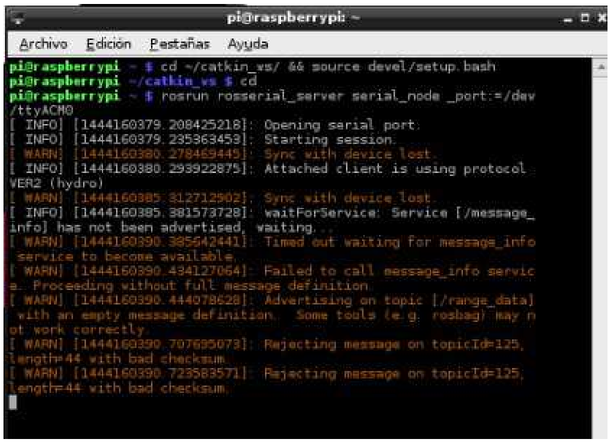

Figure 18. Opening the workspace.

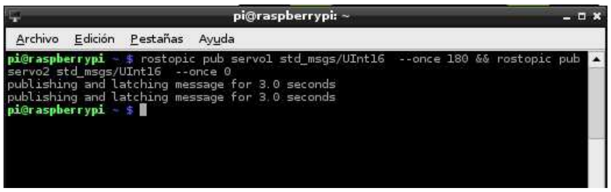

Figure 19. Control of the direction and speed of the servomotors.

The above command indicates that both servomotors, servo1 and servo2, move in the opposite direction at maximum speed.

Rqt_plot Application: The rqt_plot tool works with two-dimensional graphics, where a sample of the signal taken by the infrared sensor when it detects a near object within a radius of five cm is displayed. To enter this tool the following code is written in a separate terminal:

```
$ rqt_plot range_data/range
```

Fig. 20 shows the graph showing the infrared sensor by means of the Rqt_Plot function.

Navigation task

We implement a basic navigation task in unknown, static and observable environments. The SERB robot is programmed to perform displacement by means of two servomotors, which are monitored by means of a computer and the operating system ROS OS. When it is close to an obstacle, it will be detected by the robot by means of the infrared sensor, which sends the signal to ROS OS, which indicates to stop the robot, to turn one of its wheels in the opposite sense to the direction to which it moves. This causes a turn in the robot which after a second is put back into gear, advancing again with their wheels driven by servomotors 1 and 2.

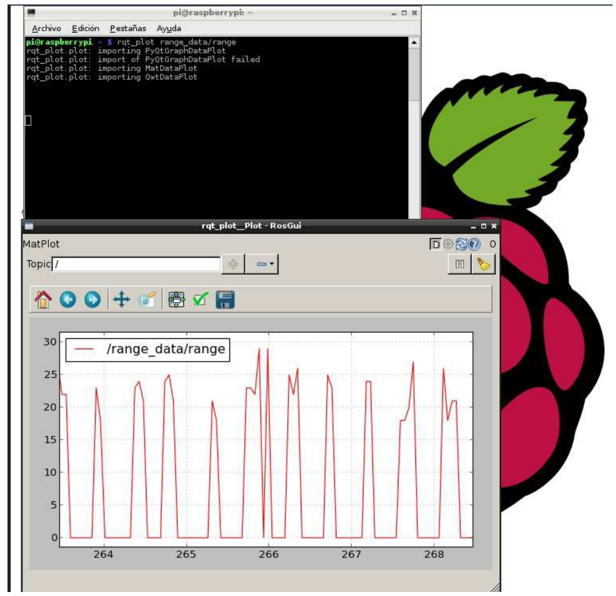

Figure 20. Sample plot of function `Rqt_Plot`.

Results and performance on SERB robot

The first result obtained is the interface achieved through Raspberry Pi with Raspbian and ROS OS with the version ROS Groovy Galapagos, for which to perform the steps exposed the synchronization can be given in a time of 8 s. However, the different times of execution of the programming of the robot are expressed below:

- Starting time of the Raspberry PI: 62 s (time needed to start communicating our pc and the Raspberry Pi through the Putty program).
- Starting Roscore 8 s (time required to open ROS in a Raspbian terminal).
- Communication ROS and Arduino 15 s (time required to link the communication of the Arduino board with ROS through a Raspbian terminal).
- Servo control 4.9 s (time required by a ROS command to control the direction or speed of a Servo).
- Control of a second servo 13 s (time taken by the second servomotor in the same order sent by ROS).
- Time opening Rqt-plot 58 s (time spent by the Rqt-Plot application to open and show the signal of an obstacle).

With this, it can be observed that the response times of the robot to sent orders are not immediate due to processing tasks of the Raspberry Pi that can become saturated with this type of applications.

The independence level of the SERB robot is reached thanks to the independence in the power supply and the control exercised remotely, for this reason, the power supply is through 2 chargers of 5 V and 0.5 to 0.7 A, which independently feed the Raspberry Pi board, the Arduino Uno board and the infrared sensor, as well as the second charger,

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is in charge of supplying the motion energy for servomotor 1 and servomotor 2, this means of feeding provides the degree of freedom for the robot to move autonomously over the entire navigation platform.

The level of control implemented in this robotic application exceeds the performance and specifications previously studied since the robot does not simply avoid obstacles but it can provide a desired or specific trajectory, this is achieved through remote control with the Putty program, so the observation or detection of objects is done in an average time of 58 s.

Extensions and issues

ROS OS is an operating system with little time on the market when compared to systems like Ubuntu, Windows and Linux nevertheless presents variety in its product so the versions to work are characterized by its tools and specific depending on the requirement of the programmer, for such reason the version used for the execution of the robotic application must comply with the interface between Raspberry Pi and ROS OS, reason for which tests were made of installation of ROS OS Indigo Igloo developed in 2014 and ROS OS Hydro Medusa designed in 2013 on the board, obtaining erroneous results at the time of verifying its compatibility, where the main reason is that these updates or versions of the program are developed by fans of the ROS community, so one of its main shortcomings are the outdated repositories which have the execution error on the Raspbian platform.

The navigation task is based on the detection of objects in order to avoid and take a new direction of movement, for this was taken into account the ultrasound sensor of Arduino HC-SR04, which is used in different robotic applications based on Arduino, but when this sensor is implemented with the card and the ROS OS system we identify that the operating system ROS OS Groovy Galapagos is not compatible with the sensor, we conclude that the sensor does not meet the interface characteristics necessary for the harmony of the system in general, for this reason we implement the infrared sensor IR GP2Y0A41SK0F which is recommended on the official website `www.ros.org`, where the adequate sampling or data collection is obtained for the performance of the robot.

The Raspberry Pi board model B, presents better capacity and resources than the model A, however in the design of the robotic application the idea considered the use of 2 sensors for better navigation and that the robot will perform in a more versatile way to more complex platforms, but when we observe the performance of the sensor and its tool rqt-plot on the plate we find that the resources needed for the robotic application are 100 percent. This optimizes resources by centrally locating the infrared sensor IR GP2Y0A41SK0F in the robot.

Conclusions

The robotic application designed is based on the interface developed between the Raspberry Pi board and the operating system ROS OS, this innovation is achieved through constant research in projects and robotic applications having as support any of these tools or linking them to verify their performance. The interface is based on an old version of ROS OS as it is ROS OS Groovy Galapagos designed in 2012, but as already specified the most current versions have repository problems or lines of code, additionally the working model of ROS is through spaces or folders generated from specific codes for its proper functioning, but it is necessary to add the communication between these two valuable programs which are: Raspbian and ROS OS, for this reason, to take the first steps with the different peripherals was complex because of the reduced ports provided by the board but at the same time a challenge to find and synchronize the best way of working of the board taking advantage of the benefits described above.

During the investigation the monitoring, control or command through a personal computer was one of the key points to find the connection between different equipment such as modem, cell phones and personal computers, reason why the VNC server, Putty and other features were basic and essential for progress and not dependent on the peripherals when executing the task in navigation. The next step consisted in obtaining compatibility of the Arduino board being one of the factors with greater facility to be able to carry out the programming of the robot through angles that in turn controls the servomotors that carry out the task of force, it is necessary to add that the Arduino works basically like actuator and was used by its easy or simple grammar of programming.

In the course of the project, there are many unknown factors such as the control of the SERB robot during the execution of the navigation application. Therefore, the independence achieved through 2 portable chargers, which have specific tasks or specific feeding elements, is achieved through the constant control of the infrared sensor, The idea was to work with an ultrasound sensor and not infrared, although the results were better than expected because with this new component is possible to obtain data in 2D which indicates the proximity of objects in front of the robot in a total range of 10 cm something that is suitable and sufficient for robotic displacement. The limits of the Raspberry Pi are found when we want to program the robot with two infrared sensors to obtain greater coverage at the time of moving on a given surface, which indicates that the resources are not being used in the right way or these are limitations of the board.

Finally, the aesthetics of the robot is not adequate but if functional so the robot has a degree of freedom wide enough to perform the task of navigation on a flat surface with obstacles of specific characteristics as their measures, those if the sensor fails to recognize the obstacle the task of navigation will be quite difficult.

The development of this application is a small step for the functionality and take advantage of both the Raspberry Pi board and the operating system ROS OS, with the Arduino board one of the most popular boards in the area of robotics.

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Adjustment of visual identification algorithm for use in stand-alone robot navigation applications

Ajuste de algoritmo de identificación visual para uso en aplicaciones de navegación autónoma de robots

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This article describes the adjustment of an algorithm developed by the research group for the visual identification of geometric shapes in real time on embedded systems. This algorithm was proposed inside the group, and in spite of its correct theoretical support, it presented problems when working in real applications. The purpose of the adjustment was to increase the robustness against different levels of lighting and implement it on a real robot for performance tests in the laboratory. The tasks programmed in the robot include the identification of landmarks in the environment for the activation of navigation policies. From the results achieved, a better behavior of the algorithm is observed, making its use very promising.

Keywords: Embedded system, geometric shapes, real time, visual identification

Este artículo describe el ajuste de un algoritmo desarrollado por el grupo de investigación para la identificación visual de formas geométricas en tiempo real sobre sistemas embebidos. Dicho algoritmo fue propuesto al interior del grupo, y pese a su correcto soporte teórico, presentó problemas al funcionar en aplicaciones reales. En el ajuste realizado se buscó incrementar la robustez frente a diferentes niveles de iluminación, e implementarlo sobre un robot real para pruebas de desempeño en laboratorio. Las tareas programadas en el robot incluyen la identificación de *landmarks* en el ambiente para la activación de políticas de navegación. A partir de los resultados alcanzados se observa un mejor comportamiento del algoritmo haciendo muy promisoria su utilización.

Palabras clave: Formas geométricas, identificación visual, sistema embebido, tiempo real

Article typology: Research

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Introduction

Nowadays robots have become a tool capable of carrying out tasks efficiently and with greater precision than human beings, in such a way that today the need arises to implement increasingly autonomous and sophisticated robots that are capable of simplifying human work, thus achieving greater efficiency in the development of any process that is intervened by such robots.

One of the points of greatest interest is the detection of obstacles in unmanned vehicles (Samadi & Othman, 2013) since they make use of the omnidirectional system to have a better vision in mobile robots (Lee, Feng, Yeh, & Ivan, 2013). In addition the use of artificial vision makes a great contribution to this area of research where the IBDMS method (Tsai, Chuang, Lu, & Wang, 2013), helps us to determine the collision distance and the early reaction of the machine by means of a camera, as it helps us to recognition based on CAD (Louis & Ricky, 2011), all this is done with the need to maneuver in places with objects and obstacles (Samadi & Othman, 2013), the results that are obtained are very useful because they get it without using GPS, and is very well received because its implementation is in unmanned aerial vehicles (Samadi & Othman, 2013).

In addition, the approach to autonomy is very large, as it is a fundamental part of robots (Jacinto, Martínez, & Martínez, 2016). Recently an air vehicle (MAV) (Schoellig, Barfoot, & Pfrunder, 2014) is being developed, with 3D vision sensors, helps to develop a great variety of tasks without the use of GPS, this autonomous flight system presents great success in its tasks of path planning and exact positioning.

Also, the systematic development of an unmanned helicopter (Ponte, Queenan, Gong, & Mertz, 2014), makes its contribution in the detection of objects, using the hardware as vision system and being able to coordinate several tasks, giving an immediate response to the terrestrial objective in movement.

In the utility of artificial vision is necessary to make applications capable of reading data in both static and real-time images, in order to detect shapes or colors for tasks of image quality improvement or restoration of degraded images, as well as to have simple and efficient results according to the interest sought.

For the identification of figures (Aslan, Abdelmunim, & Farang, 2011), it proposes a geometric and dynamic method based on the search of forms in some sets of images. The algorithm joins the different shapes contained in these sets to make segmentation of the image. The image is transformed into a two-dimensional space, and an analysis of the main components is carried out to represent the variation of the shape and to calculate a sufficient number of possible projections in the directions that an object can have and thus carry out its detection.

Image detection obtains geometric shapes and external features of the target (Chegtian, Keyong, & Lian, 2008) in a very short distance and provides relevant information about the target. But due to a large amount of information provided in real time by the camera, sometimes there is some noise or distortion of the lens. To solve this problem, a laser indicator is used to mark the region of interest. The algorithm binarizes the image to obtain and orient the skeleton. Secondly, the shape of the lens is extracted. Finally, a mapping is performed using the WMF (Wave Mapping Feature) technique to obtain the state of the target.

In binary images, the pixel can take exactly one of two values (Burger & Burge, 2008). It is often thought that these values represent the foreground and background in the image, although these concepts are often not applicable to natural scenes. Thus we focus on regions in images and how to isolate and describe such structures. Our main task, then, is to design a program to interpret the number and type of objects in a figure. As long as we continue to consider each pixel in isolation, we will not be able to determine how many objects there are in general in the image, where they are, and whose pixels belong to which objects. Therefore, our first step is to find each object by grouping all the pixels that belong to it. In the simplest case, an object is a group of pixels taken from the foreground; that is, a connected binary region.

Algorithm development is central to image processing and computer vision (MathWorks, n.d.), as each situation is unique, and good solutions require multiple design iterations. MathWorks provides a complete environment to delve into image and video data, develop algorithms, and explore the advantages and disadvantages of implementation. These tools become essential when seeking the development of autonomous robotic applications (Martínez, Jacinto, & Zárate, 2015), particularly when used in research and education (Martínez, Montiel, & Jacinto, 2016).

A digital image is nothing more than data numbers indicating variations of red, green, and blue in a particular location in a grid of pixels (Processing, n.d.). Most of the time, we see these pixels as miniature rectangles interspersed together on a computer screen. With a little creative thinking and a minimum level of coding for pixel manipulation, we can display that information in several ways.

Problem formulation

For the adjustment of these identification algorithms, we start from a functional analysis and performance tests to the two codes previously developed by the members of the research group Jhon León and Henry Valderrama (León & Valderrama, 2016). With these algorithms, they showed results with three types of luminosity on the target, for which they reported the results of Figs. 1 to 11.

Figure 1. Low light intensity. First test performed on code 1 (León & Valderrama, 2016).

Figure 2. Low light intensity. Second test performed on code 1 (León & Valderrama, 2016).

Figure 3. Low light intensity. First test performed on code 2 (León & Valderrama, 2016).

Figure 4. Low light intensity. Second test performed on code 2 (León & Valderrama, 2016).

Figure 5. Medium light intensity. Test performed on code 2 (León & Valderrama, 2016).

Figure 6. Medium light intensity. First test performed on code 2 (León & Valderrama, 2016).

Figure 7. Medium light intensity. Second test performed on code 2 (León & Valderrama, 2016).

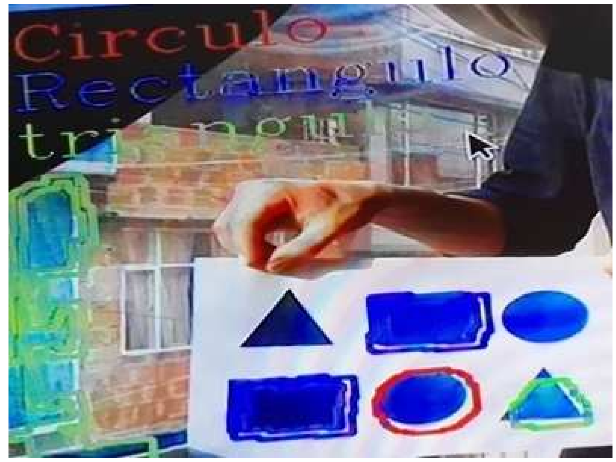

Figure 10. High light intensity. First test performed on code 2 (León & Valderrama, 2016).

Figure 8. High light intensity. First test performed on code 1 (León & Valderrama, 2016).

Figure 11. High light intensity. Second test performed on code 2 (León & Valderrama, 2016).

Figure 9. High light intensity. Second test performed on code 1 (León & Valderrama, 2016).

In order to carry out the above tests, the luminous intensity of the environment was taken into account. The lighting conditions were checked in each case with the aid of measuring instruments (luxmeter). Table 1 summarises the test results.

Table 1

Laboratory test results with initial algorithms.

Environmental characteristics	**Luminous intensity [lx]**
Low light intensity	50
Medium light intensity	370
High light intensity	730

As a final result of the performance of the two previous algorithms it was determined that the amount of light was an important factor in the recognition of the figures, since the camera exposed in this work presented a low resolution, which prevented a better response. As can be seen in the

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images taken from the tests, the best environmental condition for the recognition of these figures involves a high amount of light, and with the help of the luxometer was defined a luminous intensity of 730 lx.

As work projection from the results, we started adjustments with the first algorithm, since it presents a better recognition and detection of the figure, and also allows us to make a better redesign and implementation of the codes. It should also be noted that the camera for such work must present a better resolution and field of vision, in order to make a better recognition in any environment.

Methodology

The processing system was assembled in order to have a low-cost platform to perform the tasks of recognition and visual representation of geometric figures. The parts that compose it are (Figs. 12 and 12):

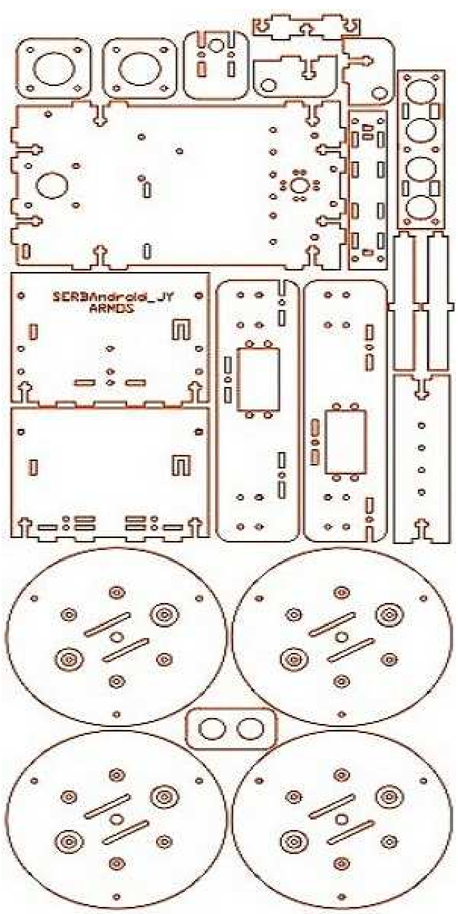

Figure 12. AutoCAD template of the robot's mechanical structure.

Figs. 14 to 30 show the assembly steps of the SERB robot.

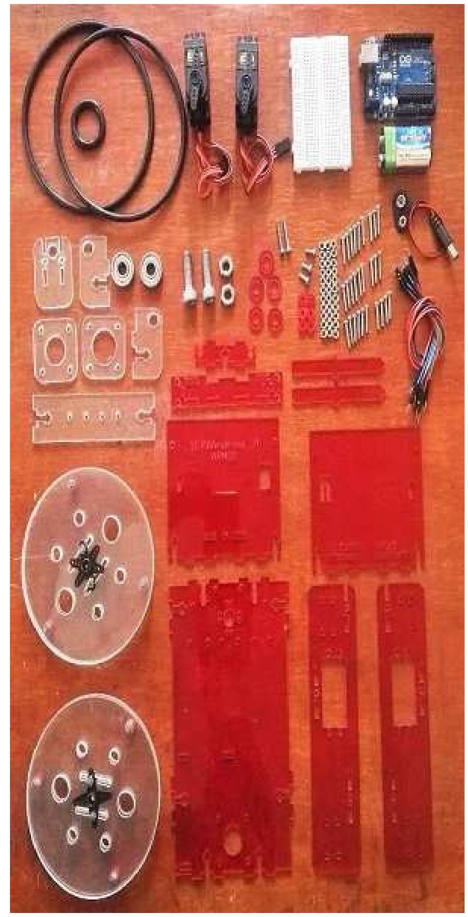

Figure 13. Parts of the robot's mechanical structure cut from acrylic sheet.

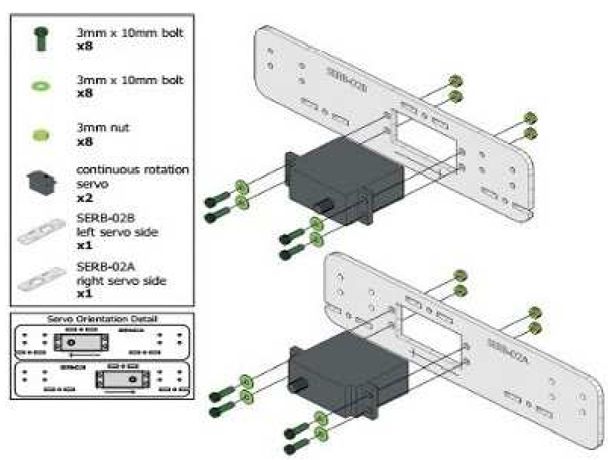

Figure 14. Assembly of servomotors Martínez, Montiel, and Valderrama (2016).

Embedded system

For the direct control of actuators and sensors, we have selected a small 8-bit microcontroller on an

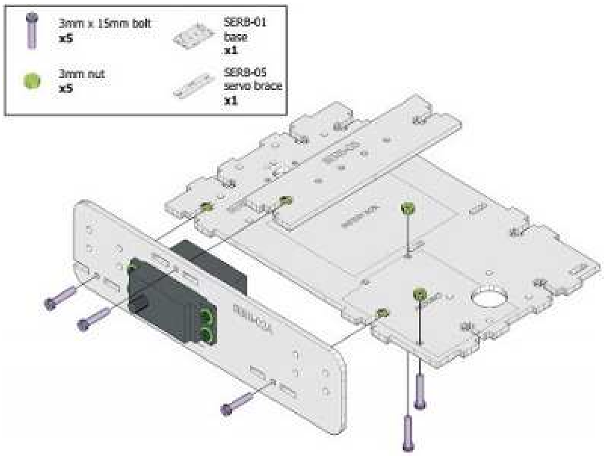

Figure 15. Protoboard mounting bracket assembly Martínez, Montiel, and Valderrama (2016).

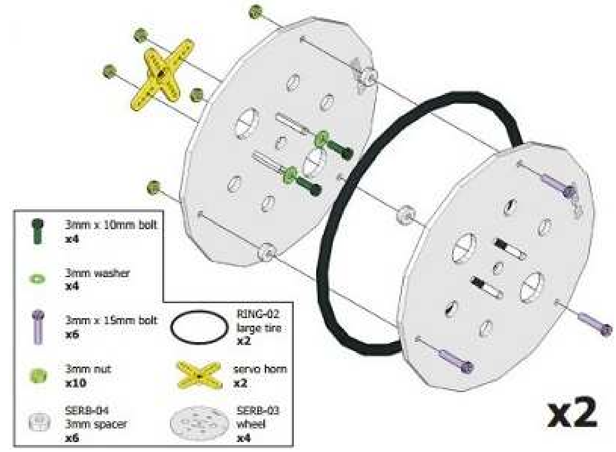

Figure 18. Wheel assembly Martínez, Montiel, and Valderrama (2016).

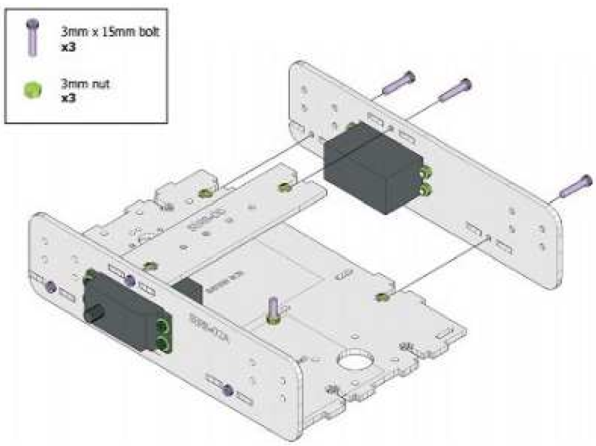

Figure 16. Main base assembly Martínez, Montiel, and Valderrama (2016).

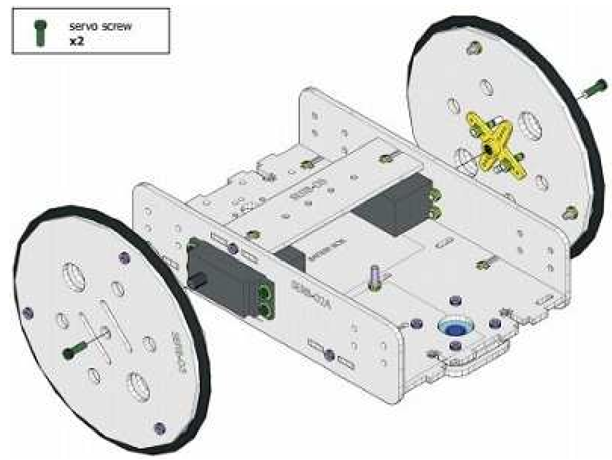

Figure 19. Assembly of the wheels on the main base Martínez, Montiel, and Valderrama (2016).

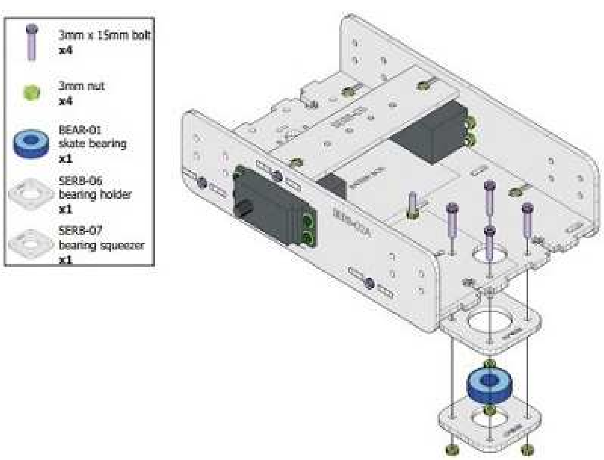

Figure 17. Support wheel base assembly Martínez, Montiel, and Valderrama (2016).

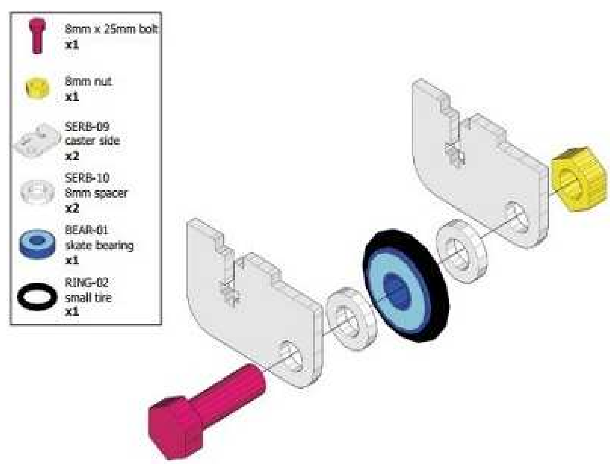

Figure 20. Support wheel assembly Martínez, Montiel, and Valderrama (2016).

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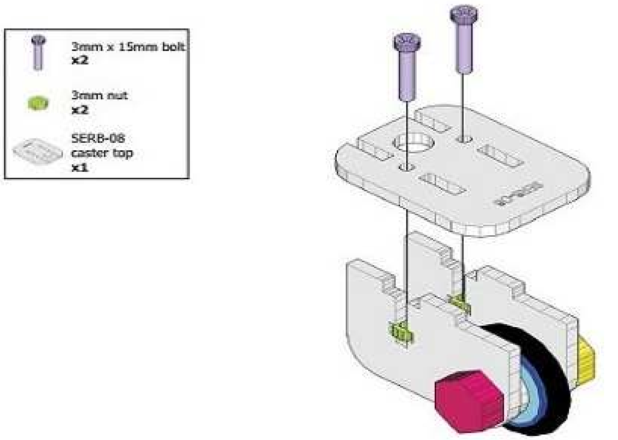

Figure 21. Support wheel bracket assembly Martínez, Montiel, and Valderrama (2016).

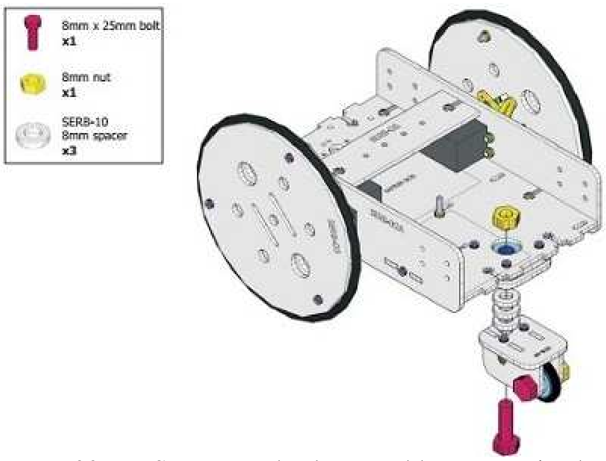

Figure 22. Support wheel assembly on main base Martínez, Montiel, and Valderrama (2016).

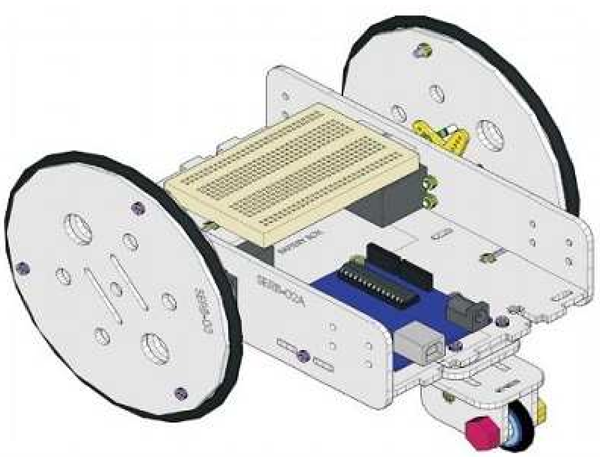

Figure 23. Scheme of the fully assembled SERB robot Martínez, Montiel, and Valderrama (2016).

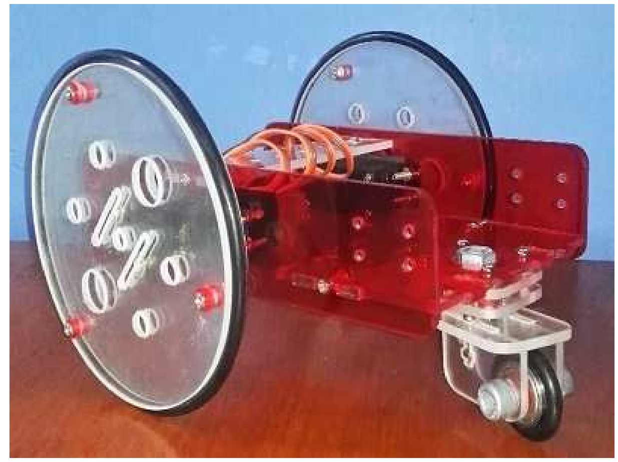

Figure 24. Real SERB Robot assembled.

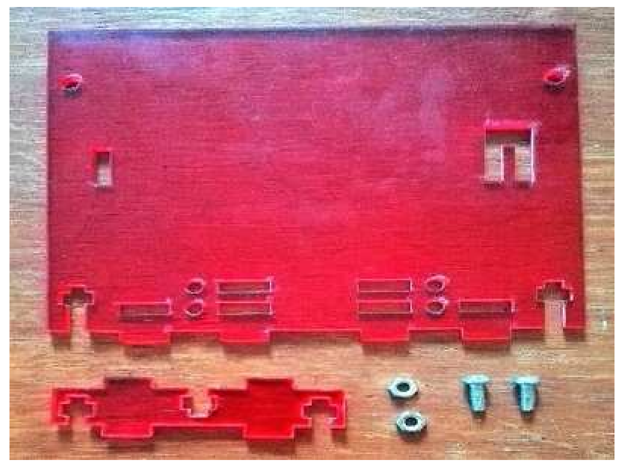

Figure 25. Front face of the support structure for the smartphone.

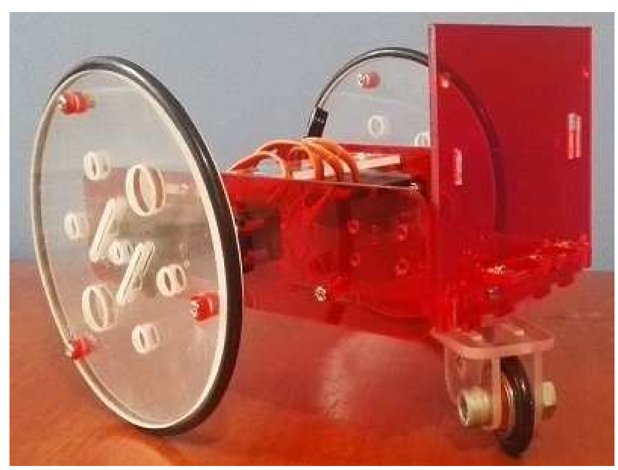

Figure 26. Smartphone bracket front face assembly.

Arduino/Genuino board. The system consists of an ATmega328P microcontroller. It has 14 digital input/output pins (6 of which can be used as PWM outputs), 6 analog

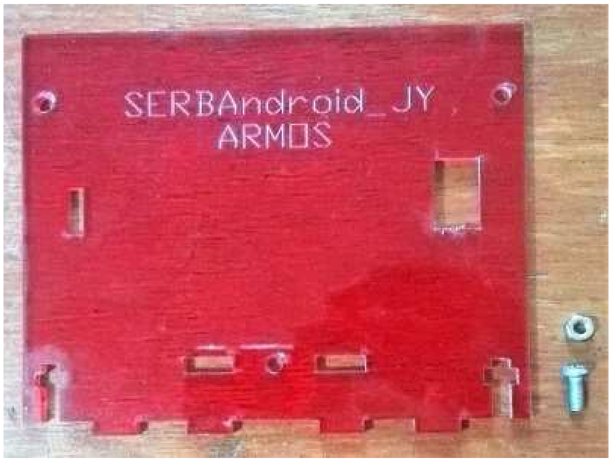

Figure 27. Rear face of the support structure for the smartphone.

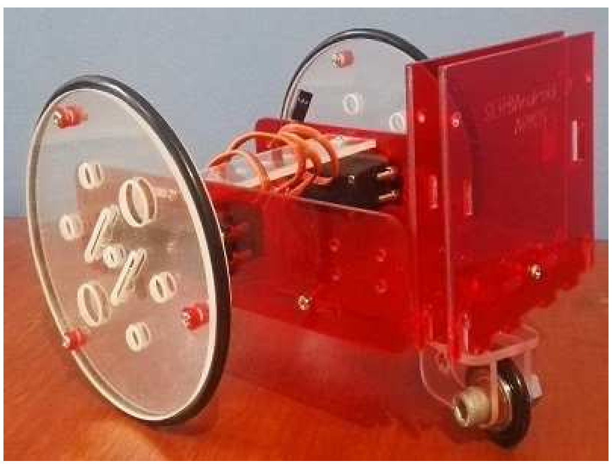
Figure 28. Smartphone bracket rear face assembly.

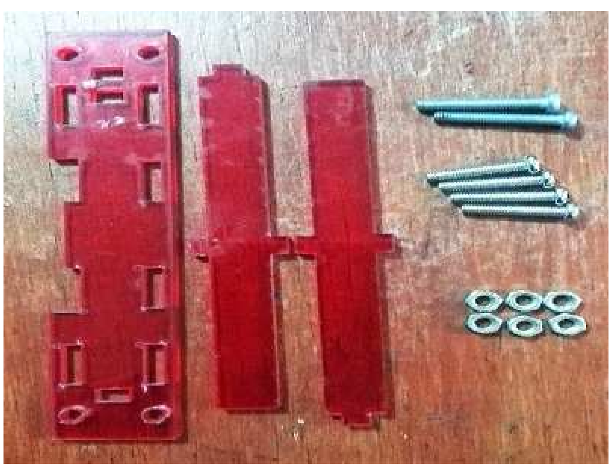
Figure 29. Front and rear face support.

inputs, a 16 MHz crystal, a USB connection, a power connector, an ICSP header, and a reset button. This is programmed by means of its own IDE, in a language that

Figure 30. SERB robot fully assembled with smartphone holder.

is a variant of C/C++. It is linked to AVR Libc, a library that allows the use of any of the functions of the microcontroller (Arduino, n.d.).

Android device with IP camera

With the advancement of technologies today, the IP camera has become a very functional tool in projects where it involves the use of it, has also been developed to be a very simple task to implement, and has great coverage in low-end devices as it is compatible with versions of Android 1.6 onwards.

The application must first be downloaded from the Play Store located at the following link: `https://play.google.com/store/apps/details?id=com.pas.webcam&hl=en_419`. It is then necessary that the device and the computer are connected to the same WI-FI network. You can see that the application has a variety of configurations among the most important this allow choosing the video resolution, image quality, among others. All this depends on the need for which it will be used, once this is implemented, only choose the option to start the server, which generates an IP address of the type `http://192.168.0.#:8080/`, which must be implemented in the Matlab code to be able to make the image reproduction in real time.

Engineering of image processing algorithms

For the realization of the image processing algorithm for the recognition of basic geometric figures, we select as target figures the triangle, circle, rectangle, and square. This algorithm has been rewritten under the Matlab environment (the original code is written in Python) and was adjusted so that it only detects blue figures, regardless of the background

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texture. In this way, better results are obtained in the identification of the figure.

The figure detection process consists of several stages. First, the algorithm finds a rectangular bounding box for each region. The bounding rectangle can be oriented with an arbitrary angle using the `minbounrect` function (Matlab toolbox) and will take the following approaches for each geometric shape (Fig. 31).

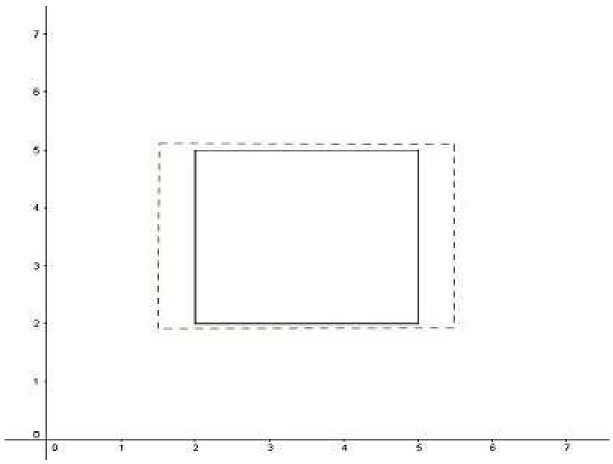

Figure 31. Approximation of detection square geometric shape.

The square detection takes into account the aspect ratio between width and height of the rectangular box found thanks to the `minboundrect` function (Matlab toolbox). The shape of the square is almost proportional to the shape of the rectangular box, therefore it is necessary to identify the aspect ratio width/height with a value below the unit. On the other hand, when compared with the other geometric shapes, it will be close to the unit by approximately 80%.

For the detection of the triangle, the area of the rectangular box found is taken into account, as well as the area occupied by the triangular-shaped region. Therefore, the metric relation of the triangle is assigned as (area of the region)/(area of the rectangular box). The space occupied by this form shall not exceed 60% with respect to the space occupied by the area of the rectangular box. Thus we take as values lower than 60% the geometric shape of the triangle, which in turn will serve to be compared with the other geometric shapes (Fig. 32).

The detection of the circle takes into account the metric relation of the perimeter of the circle for the regions found. This ratio produces numerical values greater than one, so it is greater than the width/height ratio of the rectangular box found and in turn the area occupied by it. This will differentiate it from other geometric shapes (Fig. 33).

For the identification of the rectangle is taken into account its closeness according to the aspect ratio of height/width of the rectangular box found, so the proportional value will be very close to the unit (Fig. 34).

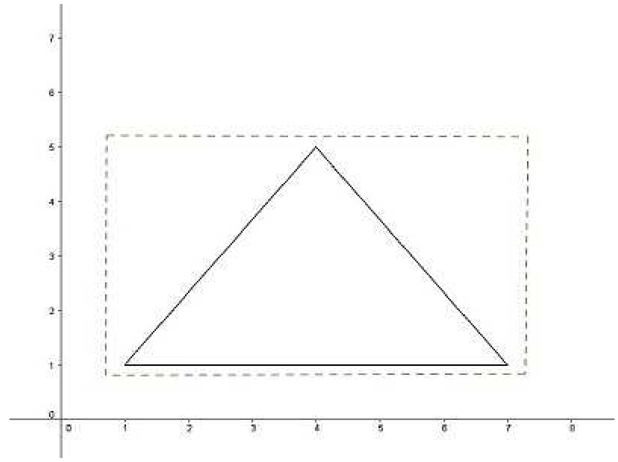

Figure 32. Approximation of detection triangle geometric shape.

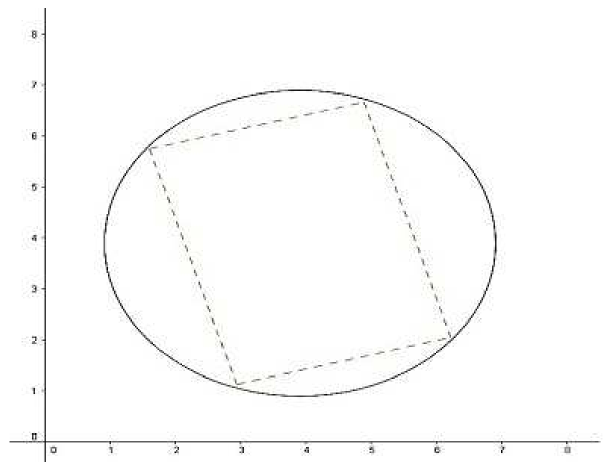

Figure 33. Approximation of detection circle geometric shape.

Deployment

The operation of the algorithm is shown in the flow diagram in Fig. 35. The figures shown in Fig. 36 were used for the laboratory tests.

Figs. 37 to 42 show the result of the step-by-step processes applied to the image in Fig. 36.

The flow diagram in Fig. 43 correspond to the final process of labeling regions and determining the geometric figure.

According to the results of the tests carried out on the original algorithm, and in addition to what was stated in the initial work (León & Valderrama, 2016), we assume the following elements as the basis for the adjustment of the

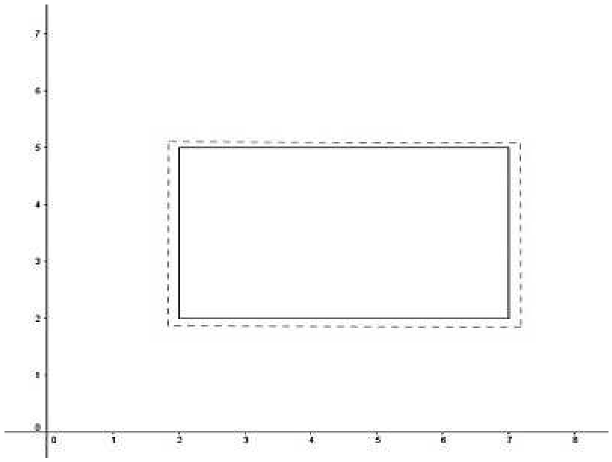

Figure 34. Approximation of detection rectangle geometric shape.

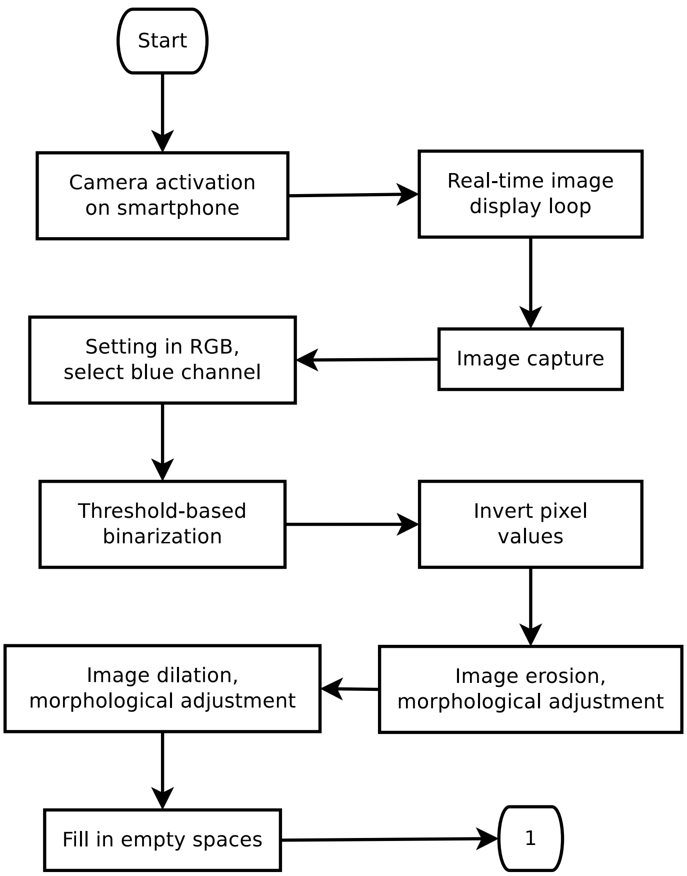

Figure 35. Flowchart of the geometric figure identification algorithm.

Figure 36. Geometric test figures.

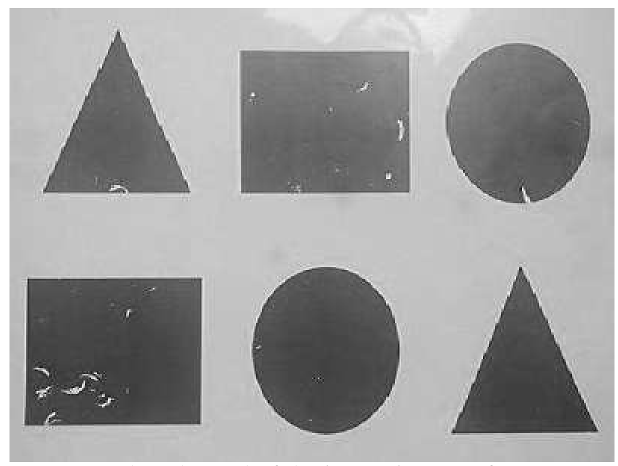

Figure 37. Blue channel of the image in RGB format.

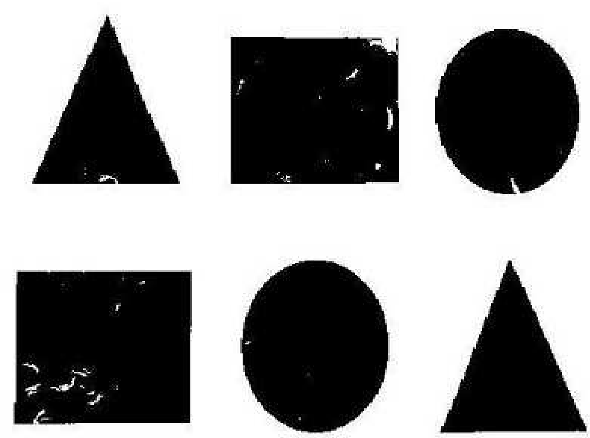

Figure 38. Binarized image.

algorithm in order to improve the detection of geometric figures.

One of the aspects attacked for the improvement was the device used for the process of capture of the real environment, for the case of Leon and Valderrama (León & Valderrama, 2016), was used the Raspberry Pi Model B+ board, offering limitations in its peripheral device of visualization, its 5 Megapixel camera. For our case, we

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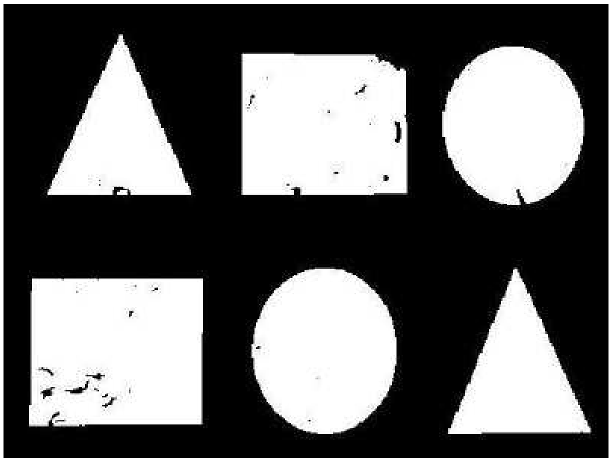

Figure 39. Inverted binary image.

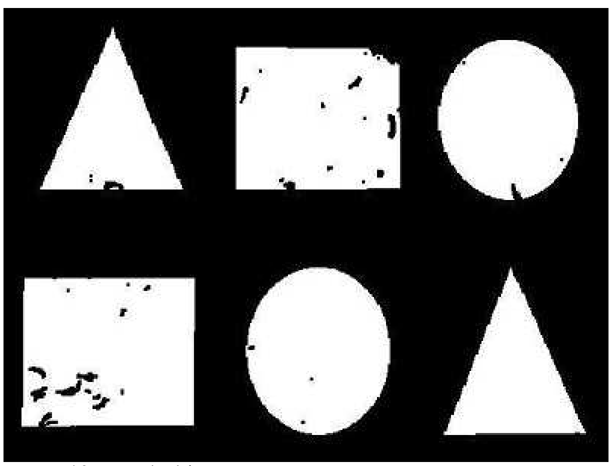

Figure 40. Eroded image.

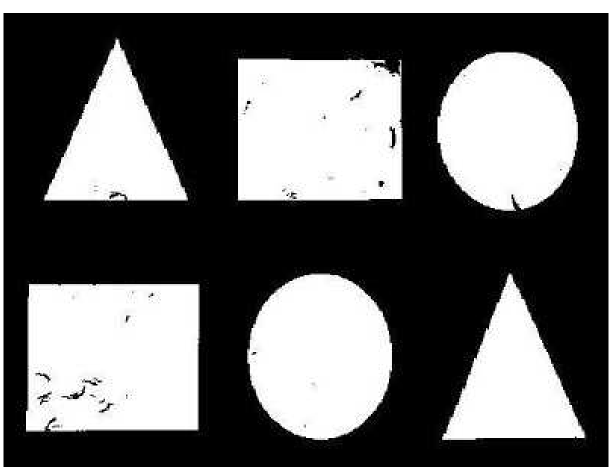

Figure 41. Dilated image.

have as the device of capture the camera of a Smartphone, which thanks to the application used (IP Webcam) allows the

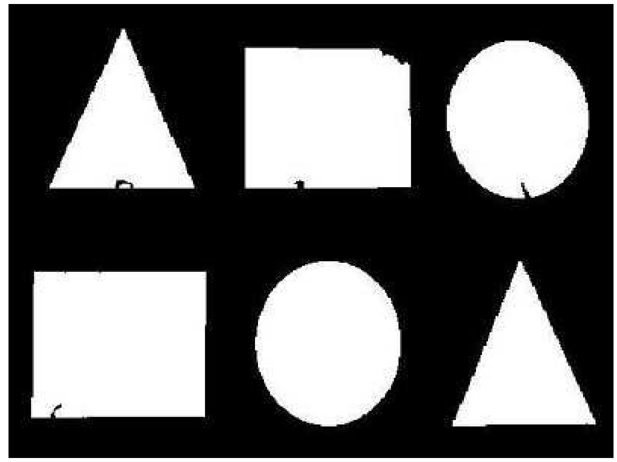

Figure 42. Filled image, ready to be labeled.

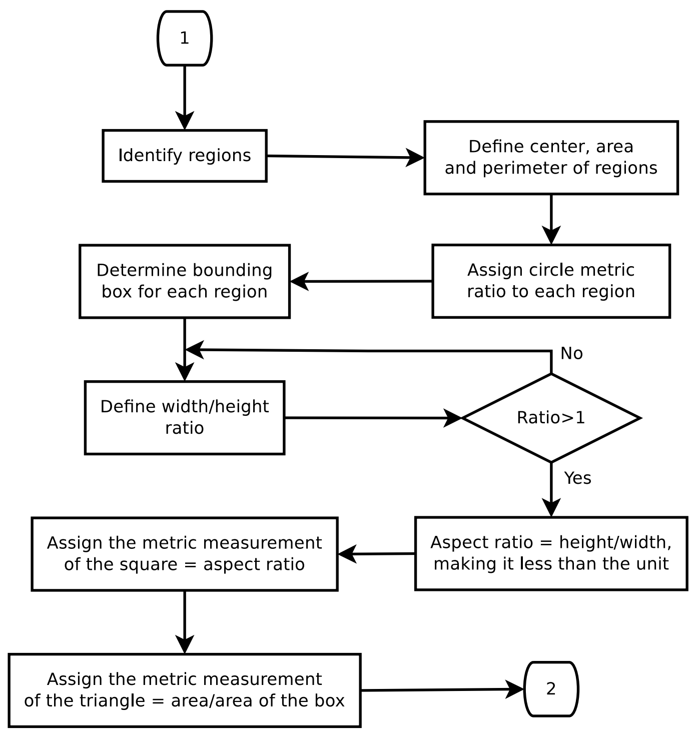

Figure 43. Labelling of regions.

use of the resolution of the camera between 8 Megapixels to 13 Megapixels.

The image format is one of the important elements for image processing. A certain format allows some easiness in operations that minimize the search of what we need, or it allows to transform the image to convenience. In the case of León and Valderrama (León & Valderrama, 2016), HSV was used and for our case the RGB format. For the RGB format, we take into account the intensity of the primary colors of the light (Mingjing, Lili, & Jingke, 2010), in HSV is taken into account the degradation in the colors seen by the RGB but in terms of Hue (given in degrees) and saturation (given in percentage) (Santos, Marcolino, Lopes, Matheus, & Assis, 2016).

To correct irregularities in the image, it is necessary to use methods based on morphological operations, such as erosion, dilation, and filling of shapes that give a soft touch to the image, allowing the search to be minimized. In the case of León and Valderrama (León & Valderrama, 2016), as well as our case, the same operations were used.

The detection of shapes varies in the parts, both for Leon and Valderrama and for us. The approach of León and Valderrama (León & Valderrama, 2016), was to analyze from the contours (edges) of the filtered areas according to the color channel, at the same time compared with a polynomial approximation according to the found contours taking into account the number of points contained in the found contour, with this established the geometric figure. On the other hand, the second algorithm took into account the contours but measured the length of the found contours and compared them with the shape of a circumference drawn in a theoretical way. Then, according to a comparison of excess areas, the geometric figure is determined.

In our case, we take into account the labeling of regions or search for regions, in which mathematical relations are carried out that compare their results below or above the unit due to a minimum rectangle found for each region. There is a similarity with that used by León and Valderrama (León & Valderrama, 2016), in their second algorithm.

It is important to use robust software with the ability to perform image processing effectively. For the case of Leon and Valderrama (León & Valderrama, 2016), they were supported in Python and the OpenCV 2.4.11 API on the Raspbian operating system, which uses the Raspberry Pi Model B+ embedded system. This generated some difficulty in real-time image processing, as its response speed is somewhat slow. In our case, and as a strategy to increase performance, the platform used was the Android operating system in a mid-range Smartphone. This allowed the installation of the right application to give usefulness to the camera, at the same time taking advantage of by MATLAB.

The performance of the León and Valderrama (León & Valderrama, 2016) algorithm, evaluated in this research, showed irregularity according to the luminous intensity of the environment. Its detection is optimal at higher luminosity, but in medium and low luminosity the detection deteriorates. At the same time, the detection is limited to three or four areas found. For our case, we used an average threshold in the blue channel of the RGB format, which behaves in a stable way to medium and high light intensity. On the other hand, region detection helps us to obtain more detected shapes.

Results and performance

The algorithm implemented in Matlab, and with the help of the high-resolution camera of the Smartphone, was achieved the recognition of the desired figures. Some of the results achieved are shown below (Figs. 44 to 47).

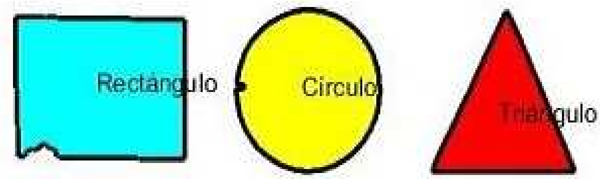

Figure 44. Three figures case 1.

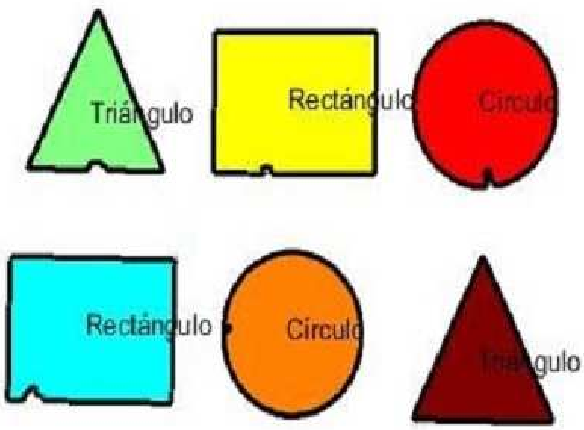

Figure 45. Six figures case 1.

Figure 46. Three figures case 2.

It is observed that the recognition of the figures of the form one paints of a random color the found regions. For this case, it corresponds to geometric figures specifying the name of each one. In the second form, a border is made on the image of green color and also indicating us the name of each one of them.

Conclusions

We designed a low-cost prototype very versatile, which allows us to make a better sketch and recognition of the desired geometric figures. The real-time geometric figure recognition strategy is based on a bounding rectangle. This

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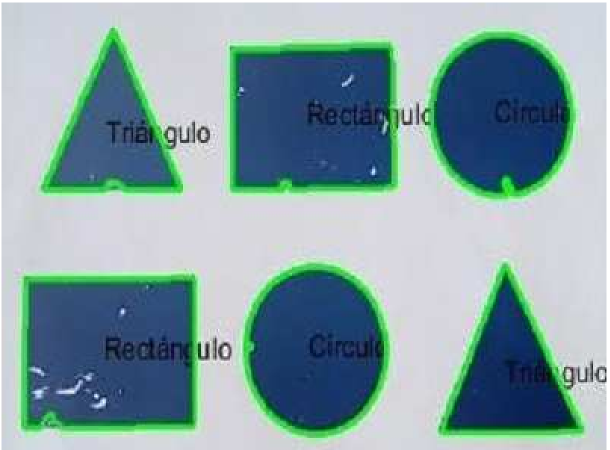

Figure 47. Six figures case 2.

is formed from the regions found and allows to determine the figure that is in it thanks to the minbounrect function (Matlab toolbox). It is useful when the contour of the figure is continuous, i.e. there are no cut lines and it works for closed regions. Each of the proposed objectives was achieved, providing an improvement in the recognition of geometric figures with respect to previous algorithms. We determined that our algorithm is 20% faster for figure detection using Matlab than Python and OpenCV. In terms of performance, this new implementation has a very low margin of error and less sensitivity to the luminous intensity of the environment. However, since the development goal is to achieve an embedded solution for small robots, it is necessary to continue this research in order to implement the algorithms on a smaller platform.

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We thank and recognize both the Universidad Distrital Francisco José de Caldas in general, as well as the ARMOS research group, which gave us its collaboration and support during the realization of the project. The ideas and postulates described here do not compromise in any way the opinions of either the District University or the ARMOS research group.

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Instrucciones para los autores

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Formato del manuscrito

En cuanto a estructura, deben ser evidentes las secciones de introducción, metodología, resultados, conclusiones y referencias. El resto del documento se debe conformar en concordancia con su contenido. La longitud no debe superar las 25 páginas en su totalidad. En la parte inicial de la primera página se debe incluir: (1) Un título del manuscrito (en español e inglés), corto, descriptivo del contenido y atractivo para el lector. (2) Nombre completo de los autores y detalles de afiliación institucional, incluido correo electrónico. (3) Resumen (en español e inglés) del manuscrito con un tamaño máximo de 250 palabras, que establezca el objetivo, la metodología, los resultados y principales conclusiones. (4) Palabras claves, máximo cinco, en minúsculas y separadas por comas.

En cuanto al formato de documento solicitado a los autores, se pide no utilizar estilos de los procesadores de textos. El manuscrito debe estar a una columna, a espacio sencillo entre líneas de texto y sin dejar espacio entre párrafos y entre títulos y texto. Se debe seleccionar papel tamaño carta (21 cm de ancho por 29.7 cm de largo), en forma vertical. Los márgenes deben ser 2 cm en todos los lados (izquierda, derecha, arriba y abajo). Se debe usar letra Times New Roman (si no se posee, utilizar una de tipo serif similar) sin reducción de espacio entre caracteres, con tamaño de 12 puntos. Por ningún motivo se aceptarán trabajos que incluyan letras, palabras o símbolos manuscritos en el texto. Las tablas y figuras deben ser claras y nítidas, insertadas (no pegadas) en el documento como un único objeto (no agrupación de varios) con la mayor calidad posible. Se pide que estas figuras sean remitidas en un archivo comprimido por separado. Si se usan líneas o figuras en colores, no se debe usar colores claros (amarillos, celestes y similares). El Editor se reserva el derecho de eliminar toda figura o tabla que no cumpla las normas. Toda figura, tabla, ecuación o referencia incluida en el manuscrito debe estar referenciada/citada en el cuerpo del documento. No se debe usar sangría en ninguna sección del artículo. Las referencias deben manejar correcto estilo APA sexta edición. No se deben utilizar notas al pie de página, y usar máximo tres niveles para los títulos. Se puede incluir una sección de Agradecimientos (altamente recomendada), redactada en forma sobria, de no más de cuatro líneas justo después de las Conclusiones.

En cuanto al formato del archivo fuente, se puede utilizar cualquier procesador de textos, siempre y cuando el contenido sea completo y editable (no se permite archivos *.txt). Los formatos recomendados son: *.rtf, *.doc, *.docx, *.odt, *.wpd y *.tex. En caso de utilizar LaTeX, se deben remitir todos los archivos fuente. Para todos los casos, los autores deben remitir, junto con las imágenes, un archivo BibTeX (un único archivo *.bib) con todas las referencias utilizadas en el artículo, cada referencia con una key única. Este archivo puede ser generado desde manejadores de referencias como Mendeley y Zotero, o generado con herramientas como JabRef.

En cuanto al lenguaje y estilo de redacción, se deben utilizar oraciones simples y evitar regionalismos. Se debe poner especial cuidado en el correcto uso de la ortografía y redacción, de acuerdo a las reglas del lenguaje.

Formato de publicación

Los manuscritos son publicados siguiendo el estilo APA sexta edición. Esto es realizado en la diagramación, y es transparente para los autores.

Cambios en la edición

El Editor se reserva el derecho, y así lo acepta el(la)(los) autor(a)(es) con el sólo envío del manuscrito, de realizar modificaciones con el objeto de lograr una mejor presentación e impacto del trabajo. Estas modificaciones pueden incluir cambios en el título, resumen, palabras clave, figuras, tablas y texto, entre otros, cambios que no afectan, según el Editor, la esencia del trabajo enviado por los autores. En particular, figuras que no pueden ser bien reproducidas pueden ser eliminadas por el Editor. Las referencias incompletas serán también eliminadas por exigencias de las bases de datos.

Envío de manuscritos

Los autores deben enviar sus artículos a través de la aplicación para tal fin del Open Journal System (http://revistas.udistrital.edu.co/ojs/index.php/tekhne/index) en formato digital, adjuntando:

• La carta de presentación.
• La carta de cesión de derechos (según formato).

La carta de presentación debe estar dirigida al director y editor de la revista, Ing. Fredy H. Martínez S., y debe incluir:

• Solicitud expresa de considerar el artículo para publicarlo en la revista Tekhnê.
• Título completo del trabajo.
• Nombres completos de todos los autores, con detalle de entidad a la que se encuentran vinculados, dirección e-mail institucional, títulos académicos, ciudad y país.
• Certificación de la originalidad y el carácter inédito del artículo.
• Exclusividad de su remisión a la revista Tekhnê.
• Confirmación de la autoría con la firma de todos los autores.
• Institución que financió o avaló el proyecto.

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2. Registro de los datos. Se regista en el OJS los datos básicos de los autores y del artículo.
3. Envío de Archivos Complementarios. Todos los archivos complementarios se envían en un único archivo comprimido. Estos archivos complementarios incluyen: los archivos fuente del documento, tanto texto como imagenes en alta calidad, archivo BibTeX con todas las referencias utilizadas, la carta de presentación, y la carta de cesión de derechos.

Proceso de publicación

El proceso que sigue la revista para la evaluación y publicación de trabajos es el siguiente:

• Recepción del manuscrito (primera versión, convocatoria permanente)
• Verificación de normas por parte de auxiliar de la revista
• Notificación a autores de recepción, solicitud de ajustes de forma y de diligenciamiento de formato de datos de autores
• Recepción de manuscrito (segunda versión) y formato de datos de autores
• Revisión por parte del Comité Editorial
• Notificación a autores de si el manuscrito entra o no a evaluación por parte de pares
• Envío de manuscrito a pares seleccionados
• Recepción de evaluación de pares
• Notificación de evaluación a autores, y solicitud de correcciones si son pertinentes
• Recepción de manuscrito (tercera versión)
• Estudio de manuscrito corregido por parte del Comité Editorial
• Notificación a autores de decisión final de publicación y solicitud de carta de cesión de derechos
• Recepción de carta de cesión de derechos
• Corrección de estilo y diagramación del manuscrito
• Envío de versión final a autores para verificación de errores y aprobación final
• Publicación del artículo
• Notificación a autores de publicación
• Entrega de ejemplares a autores

Contacto

Para cualquier solicitud de información adicional puede comunicarse con:

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Instructions for authors

Tekhnê

Tecnología al servicio de la sociedad

Universidad Distrital Francisco José de Caldas - Facultad Tecnológica

Tekhnê Journal
Universidad Distrital Francisco José de Caldas
Facultad Tecnológica

Scope and editorial policy of the journal

The Tekhnê journal is an institutional journal of the Technological Faculty of District University Francisco José de Caldas (Colombia). It is arbitrated, and accepts original articles in the field of engineering, technology and applied sciences on the condition that they are the product of research work. Since its first issue in 2003 the journal has maintained its regularity.

It has a scientific-academic nature and attends the specialist national and international community in the areas of electrical, electronics, mechanical, systems, industrial and civil engineering. Publishes research results in English (original and unpublished articles), and is fully open to experts from around the world as authors and/or readers. It is arbitrated by a double-blind process, with continuous rotation of evaluators.

The Tekhnê journal has twice a year periodicity, coinciding with the academic semesters of the District University. The publication is made in June and December each year. The evaluation process of the papers submitted for publication includes a stage of initial acceptance by the Editorial Committee, which verifies compliance with the editorial parameters and an evaluation by academic peers through a double blind process. The time taken to decide on the acceptance of a paper never exceeds six (6) months from the date of receipt.

The Tekhnê journal is committed to high ethical standards and take possible measures to avoid bad practices such as fraud and plagiarism. All authors must declare that their manuscripts are original, unpublished and of his own, needed condition to be considered by the Editorial Committee. The Tekhnê journal also is committed to ensuring a fair, objective and quick review of manuscripts both referees as by the Editor. The authors recognize that they have disclosed any actual or potential conflict of interest with their work or partial benefits associated through the transfer of rights.

The Tekhnê journal is funded by the District University Francisco José de Caldas, which is why it does NOT charge for processing and/or publishing articles (APCs).

Types of articles accepted

The journal publishes only Scientific and Technological Research articles (as classified by Publindex, the National Abstracting and Indexing System for Serial Publications in Science, Technology and Innovation of Colciencias), which are characterized by original results of completed research projects with clearly distinct sections of introduction, methodology, results and conclusions. Other articles as called reflection, review, short articles or case reports are not accepted and will be rejected by the Editorial Committee without dispensing any evaluation process.

Manuscript format

Regarding the structure, should be evident the sections of introduction, methodology, results, conclusions and references. The rest of the document must conform in accordance with its contents. The length should not exceed 25 pages in full. In the initial part of the first page should include: (1) A manuscript title (in Spanish and English), short, descriptive of the content and attractive to the reader. (2) Full name of the authors and institutional affiliation details, including email. (3) Abstract (in Spanish and English) of the manuscript with a maximum size of 250 words, which set the objective, methodology, results and major conclusions. (4) Keywords, up to five, lowercase and separated by commas.

Regarding the document format requested, authors are asked not to use styles of word processors. The manuscript must be on a column, single space between lines of text without space between paragraphs and between titles and text. Must be selected letter size paper (21 cm wide by 29.7 cm long) vertically. Margins should be 2 cm on all sides (left, right, up and down). Must be used Times New Roman (if the font is not available, use a similar serif type) without reducing character spacing, of 12 points. No articles including letters, words or symbols handwritten in the text will be accepted. Tables and figures should be clear, inserted (not pasted) in the document as a single object (no grouping of several) with the highest possible quality. It is requested that these figures are sent in a separate zipped file. If lines or color figures are used, you should not to use light colors (yellow, light blue...). The Editor reserves the right to remove any figure or table that does not meet the standards. Every figure, table, equation or references in the manuscript should be referenced/cited in the document body. Should not be indented any section of the article. References should handle right APA format 6th Edition. Do not use footnotes, and maximum to use three levels for titles. You can include an Acknowledgments section (highly recommended), written soberly, of no more than four lines, right after the Conclusions.

Regarding the source file format, you can use any word processor, as long as the content is complete and editable (*.txt files are not allowed). Recommended formats are: *.rtf, *.doc, *.docx, *.odt, *.wpd y *.tex. When using LaTeX, the author must submit all source files. In all cases, the authors must submit, along with the images, a BibTeX file (a single *.bib file) with all references used, each reference with a single key. This file can be generated from reference managers like Mendeley and Zotero, or generated with tools such as JabRef.

Regarding the language and style of writing, the author must use simple sentences and avoid regionalisms. He must take special care to use the correct spelling and writing, according to the rules of language.

Publication format

The manuscripts are published following the APA style 6th edition. This is done in the layout, and is transparent to the authors.

Editing changes

The Editor reserves the right, and is accepted by the author(s) with the only article shipping, to make changes in order to achieve a better presentation and impact of the work. These modifications may include changes in the title, abstract, keywords, figures, tables and text, among others, changes that do not affect, according to the Editor, the essence of the work submitted by the authors. In particular, figures that can not be well reproduced can be eliminated by the Editor. Incomplete references will also be eliminated by demands of databases.

Sending manuscripts

Authors must submit their articles through the application for the purpose of the Open Journal System (http://revistas.udistrital.edu.co/ojs/index.php/tekhne/index) in digital format, attaching:

- The presentation letter.
- The transfer of rights letter (according to format).

The presentation letter should be addressed to the director and editor of the journal Prof. Fredy H. Martínez S., and it should include:

- Express request to consider the article for publication in Tekhnê journal.
- Full title of the article.
- Full names of all authors, detailing entity linked, institutional e-mail address, academic degrees, city and country.
- Certification of the originality and novelty of the article.
- Exclusivity of submission to Tekhnê journal.
- Confirmation of authorship with the signature of all authors.
- Institution financing the project.

The submission process consists of three stages:

1. Sending the article in PDF format. OJS is charged with a single uncompressed file.
2. Data recording. the basic data of the authors and article are registered in the OJS.
3. Complementary files. All additional files are sent in a single compressed file. These complementary files include: the source of the document, both text and images in high quality, BibTeX file with all references used, the presentation letter, and the transfer of rights letter.

Publishing process

The process followed by the journal for evaluation and publication of articles is as follows:

- Receipt of the manuscript (first version, continuously open call)
- Verification of standards by the assistant of the journal
- Notification to authors of receipt, request for the form adjustments and filling of authors data format
- Receipt of the manuscript (second version) and authors data format
- Review by the Editorial Committee
- Notification to authors if the manuscript is sent or not to evaluation by peers
- Sending the manuscript to selected peers
- Reception peer evaluation
- Notification of evaluation to authors, and request corrections if they are relevant
- Receipt of the manuscript (third version)
- Study of manuscript corrected by the Editorial Committee
- Notification to authors of publication and final decision, and request the rights transfer letter
- Reception of the rights transfer letter
- Style correction and layout of the manuscript
- Send final version to authors for error checking and final approval
- Publication of the article
- Notification to authors of the publication
- Delivery of copies to authors

Contact

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