Automática y Robótica en Latinoamérica

Aportes desde la academia

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Cali

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Presentación

El Congreso Latinoamericano de Automática y Robótica (o *Latin American Congress on Automation and Robotics* - LACAR) nace como una iniciativa de la Red Latinoamericana de Control Automático y Robótica (Red LACAR), con el objetivo de reunir a profesionales y académicos de estas especialidades, de manera que puedan conocer y establecer contacto con sus pares en diferentes países para compartir sus logros, experiencias e investigaciones; abriendo también la posibilidad de establecer convenios de cooperación y potenciando el desarrollo de la especialidad en nuestras respectivas instituciones y países.

La Pontificia Universidad Javeriana de Cali fue la anfitriona del II Congreso Latinoamericano de Automática y Robótica (LACAR2019), evento en el cual se exploraron y discutieron los temas sobre los que se ha estado investigando a nivel latinoamericano en robótica, automatización y control; así como su interacción con otros campos del saber, sus limitaciones y los desafíos actuales. El congreso contó con sesiones plenarias, sesiones técnicas, talleres y algunos espacios que abrieron la oportunidad de compartir experiencias, discutir nuevas ideas y crear oportunidades de colaboración con colegas de la academia y la industria.

En medio de este panorama, la presente publicación compila los trabajos que fueron aceptados para su presentación en el congreso, después de haber cumplido con los requisitos de admisión verificados por pares evaluadores provenientes de reconocidas entidades de educación superior, asentadas en diferentes países iberoamericanos. En ese sentido, el objetivo principal de este libro es la divulgación de todo el conocimiento generosamente compartido por los investigadores y desarrolladores de tecnología que se dieron cita en este encuentro académico, así como ser un punto de apoyo para continuar fortaleciendo el desarrollo de la Red LACAR. Además, con el fin de favorecer y dar cabida a la participación de los diferentes países en este encuentro, la recepción de trabajos estuvo abierta en tres idiomas: español, portugués e inglés. Esta es la razón por la que en esta obra aparecen artículos escritos en diferentes idiomas.

El contenido del libro se encuentra dividido en dos secciones, que agrupan los diferentes trabajos en sintonía con los criterios y directrices emitidos por el Comité Organizador del congreso. En la primera sección, se encuentran los trabajos que muestran algunos de los resultados obtenidos en diferentes proyectos de investigación y desarrollo tecnológico, realizados por los diferentes grupos de investigación en las universidades latinoamericanas. La variedad de temáticas fue suficientemente amplia y no fue fácil definir una estrategia de agrupación, por lo que dichos trabajos aparecen en un orden alfabético del primer autor, respondiendo más a la practicidad para la identificación de sus autores que a una aglutinación en torno a una temática específica. Algunos de los trabajos están relacionados con aplicaciones de la automática y la robótica en la agricultura, mientras que otros tienen una orientación hacia las aplicaciones en la enseñanza y el aprendizaje de estas áreas del conocimiento; además, los hay relacionados con la aplicación de estas teorías en ambientes industriales.

La segunda sección del libro está dedicada principalmente a aquellos trabajos que en el momento de su presentación se encontraban en desarrollo y a los que el Comité Organizador quiso abrir un espacio para divulgar sus resultados preliminares, buscando, entre otras cosas, un intercambio de ideas que pudiera nutrir tanto a los espectadores como a los expositores. En esta sección se encuentran trabajos relacionados con aplicaciones industriales y, en mayor número, aquellos que se relacionan con aplicaciones en el campo de la ingeniería biomédica.

Adicionalmente, el Comité Editor del congreso consideró pertinente proponer a los autores de algunos trabajos seleccionados una ampliación de su contenido, para su publicación en la segunda edición del libro *Advances in Automation and Robotics Research*, que se ha convertido en uno de los logros de la Red LACAR. En esta edición del Congreso LACAR se abrió también la posibilidad de que los mejores trabajos fueran seleccionados para ser publicados en la revista *Springer Nature Applied Sciences*. Así, para brindar una mayor cobertura sobre los contenidos presentados en el congreso, la introducción de este libro hace un recuento de los trabajos realizados en diferentes universidades de todo el continente, presentados en LACAR2019.

Finalmente, en nombre del Comité Organizador del Congreso LACAR y de la Red LACAR, agradezco enormemente la confianza depositada y la aceptación que hemos tenido por parte de nuestros colegas de todo el continente; esperamos continuar con esta labor de cooperación que fortalezca nuestros lazos y nos brinde mejores y mayores oportunidades en lo académico, en lo profesional y en lo personal.

Hasta pronto,

Alexánder Martínez Álvarez

Presidente

Comité organizador de LACAR2019

Contenido

Introducción

En la actualidad, las disciplinas relacionadas con la automatización y la robótica están aportando al desarrollo de diferentes áreas, tanto productivas como de servicios. Encontramos dispositivos y sistemas robotizados y automatizados en la industria, en la agricultura, en campos relacionados con la salud humana, en la educación y en muchos otros ámbitos. Esto hace que las universidades en todo el mundo estén apostando por el desarrollo y la evolución de dichas disciplinas, además de procurar la interacción entre ellas potenciando la cooperación y el trabajo multi y transdisciplinar.

Dado que el objetivo principal de este libro es la difusión de los aportes realizados por miembros de la Red LACAR en diferentes universidades del continente americano y España, se hace pertinente mencionar algunos ejemplos del desarrollo de estas áreas del conocimiento, cuya aplicación en diversos campos hace posible su avance. En el campo de las aplicaciones de la automatización y la robótica en la agricultura, se pueden mencionar diferentes trabajos, como el realizado en el Tecnológico de Monterrey (México), donde se presenta el diseño y la implementación de un robot recolector de nuez, de bajo costo y baja complejidad mecánica, capaz de realizar los movimientos y acciones necesarias para la recolección en terrenos complejos [1].

Por su parte, en la Pontificia Universidad Javeriana (Colombia) [2] han planteado la integración de métodos conocidos de visión por computadora para identificar la etapa de madurez de las frutas Asaí, Seje y Moriche (palmas amazónicas), con base en imágenes aéreas adquiridas con un vehículo aéreo no tripulado (UAV). En esta misma área de aplicación, en la Universidad de Pamplona (Colombia) han desarrollado un trabajo en el que se identifican los primeros síntomas de la presencia de plagas en los cultivos de plantas de papa mediante la aplicación de técnicas y algoritmos de visión artificial, ayudando a los productores a reducir el tiempo y el dinero invertido en el control de dichas plagas, a la vez que se mejora la calidad de los alimentos al contener menos cantidad de productos químicos, perjudiciales para la salud de las personas [3]. Adicionalmente, un aporte interesante se efectuó en la Escuela Colombiana de Ingeniería Julio Garavito (Colombia) [4], donde se muestran los resultados de simulación de un algoritmo desarrollado para ejecutar el proceso de planeación de trayectorias de vehículos aéreos no tripulados en entornos agrícolas de forma autónoma.

Otro campo de aplicación en el que se han realizado avances en Latinoamérica es el de la prevención y gestión de riesgos. Entre los trabajos destacados en este campo está el realizado en el Tecnológico de Monterrey (México), [5] donde se proponen algunas ideas innovadoras sobre el uso de robots de bajo costo en escenarios de emergencia y se presenta el diseño e implementación de un robot articulado de tracción continua de bajo costo, bajo consumo de potencia y alta adaptabilidad a diferentes terrenos. Por su parte, en la Universidad Tecnológica de Panamá (Panamá) desarrollaron un prototipo de sistema de alertas tempranas (SAT) [6] que incluye el modelo hidráulico del río Pacora, una red de sensores para la detección de las condiciones de alerta por crecientes del río y un sistema de comunicación para la difusión de dicha alerta, que incluye a personas con discapacidad visual o auditiva.

Por otro lado, en la Universidad de Texas A&M (EE. UU.) se han realizado varios aportes en el campo de los sistemas de apoyo y promoción de la salud humana. En el primero de estos trabajos [7], se presenta una estrategia novedosa que combina la teoría probabilística bayesiana con la tecnología de realidad mixta o híbrida, para evaluar el sistema sensoriomotor de una persona. En un segundo trabajo [8], han propuesto una nueva tecnología que asista a la salud y el rendimiento de los astronautas durante las misiones espaciales de larga duración, pues aunque actualmente existen métodos para mantener el estado físico a bordo de la Estación Espacial Internacional (ISS), los resultados no son ideales. Un tercer trabajo realizado en esta universidad [9], muestra el desarrollo de una nueva metodología para la localización de campos magnéticos, cuyo enfoque podría usarse dentro del dominio de la salud y atención médica, como por ejemplo: en el espacio para monitorear a los astronautas durante la ejecución de ejercicios de fuerza y ejercicios aeróbicos, para la evaluación de terapias de rehabilitación en las personas de edad avanzada, para la evaluación de movimientos del cuerpo humano en sobrevivientes de derrame cerebral, así como también en pacientes con trastornos sensorio-motores.

En esta misma área de aplicación, el trabajo realizado en la Universidad Autónoma de Coahuila (México) [10] presenta el diseño y el análisis cinemático de un robot que podría asistir en actividades comunes de rehabilitación de extremidades inferiores, como son el movimiento de sentado a levantado y la marcha. Así mismo, con base en un trabajo conjunto entre la Universidad de Alcalá (España), la Universidad Tecnológica de Panamá (Panamá) y la Universidad Autónoma de Santo Domingo (República Dominicana) [11], se propone un sistema orientado a e-Health que sirve para pre-diagnosticar enfermedades infectocontagiosas, utilizando señales biomédicas que a su vez son útiles para la construcción de los modelos predictivos.

En cuanto al campo de las aplicaciones industriales, la Universidad Autónoma de Bucaramanga (Colombia) presenta el diseño de un banco de pruebas para realizar un proceso electroquímico de anodizado en una pieza de aluminio [12], cuyo objetivo es analizar la influencia de la solución electrolítica, la temperatura y la corriente en la formación de la capa anódica, así como controlar la temperatura y la corriente del sistema. Por otra parte, en un trabajo conjunto de la Institución Universitaria ITSA y la Universidad del Norte (Colombia), [13] se aborda el problema de encontrar el valor óptimo para hiper-parámetros, como el número de capas y el número de neuronas por capa, para una Red Neural Artificial (ANN) completamente conectada, particularmente en problemas de regresión. La estrategia de optimización propuesta se pone a prueba en diferentes conjuntos de datos relacionados con diversas aplicaciones industriales: i) predicción del rendimiento de algoritmos de exploración para robots móviles; ii) predicción de la resistencia a la compresión del hormigón; ii) predicción de la producción de energía de una planta de energía; y iv) predicción de la calidad del vino. A su vez, la Universidad de Pamplona (Colombia) [14] desarrolla un control *sensorless* para un motor de inducción, mediante un convertidor multinivel trifásico con optimización del contenido armónico en voltajes de línea.

Otros ejemplos de aplicación en la industria son los trabajos realizados en la Pontificia Universidad Javeriana (Colombia). Uno de ellos propone un procedimiento para convertir robots industriales en componentes de la Industria 4.0, de acuerdo con las pautas del Modelo de Arquitectura de Referencia para la Industria 4.0 (RAMI 4.0) [15]; otro se dedica al diseño y la implementación de una herramienta para tareas colaborativas entre humanos y robots que, desde la mirada de Industria 4.0, se denominan robots colaborativos o COBOTS [16]; y un tercero se orienta al aporte a la solución del problema de secuenciación de tareas robóticas (RTSP por sus siglas en inglés) para un robot bimanual, ya que este problema había sido estudiado por la comunidad robótica, pero solo para manipuladores de un solo brazo [17]. Por su parte, como aporte a la industria de la construcción, la Universidad Tecnológica de Panamá (Panamá) presenta un estudio [18] cuyo objetivo es proponer un modelo del comportamiento térmico de un edificio pasivo que está ventilado simplemente por ventilación natural, el cual es necesario para controlar posteriormente el confort térmico del ambiente interior a través de las aberturas de ventilación natural y persianas del edificio.

Otro campo de aplicación que ha tenido un gran auge en los últimos años es el de los vehículos autónomos, donde la cooperación entre la Universidad de Texas A&M (EE.UU.) y la Universidad Autónoma de Coahuila (México) ha dado como resultado un diseño conceptual y un análisis de simulación de un sistema aéreo modular, denominado MAS [19], diseñado con el propósito de realizar vuelo independiente y cooperativo con o sin carga útil; las propiedades de modularidad permiten que el sistema se adapte a diferentes tareas agregando o quitando módulos a una configuración modular. Además, en la Universidad de Texas A&M, se ha implementado una Red Neuronal Profunda (DNN) para distinguir gestos particulares realizados con las manos, así como también el movimiento hecho por el brazo del usuario, con el propósito de accionar actividades determinadas en un Sistema Aéreo No Tripulado (UAS) [20].

Por su parte, en este mismo campo de los vehículos autónomos aéreos, la Pontificia Universidad Javeriana (Colombia) [21] ha desarrollado un esquema de cooperación entre vehículos aéreos no tripulados (UAV), en el que se utiliza la técnica de Control por Modos Deslizantes para garantizar que el conjunto de robots sea capaz de seguir una trayectoria definida como referencia, garantizando la navegación libre de colisiones entre dichos vehículos autónomos. Respecto a otro tipo de vehículos autónomos, la Universidad Tecnológica de Panamá (Panamá) ha mostrado cómo aprovechar la resolución de la redundancia cinemática por medio de un Algoritmo Genético Multi-objetivo para la generación de la trayectoria de un Vehículo Submarino Manipulador (*Underwater Vehicle Manipulator System* - UVMS) [22].

Sumado a lo anterior, se han obtenido desarrollos y avances de corte académico o en algunos casos teórico, necesarios en el camino hacia futuras aplicaciones prácticas. Vale la pena comentar que, en algunos de los casos mencionados a continuación, ha sido muy valiosa la cooperación entre diferentes instituciones de educación superior, resaltando de esta manera la importancia del trabajo en redes académicas. Por ejemplo, la Universidad Estatal de Santa Catarina (Brasil) en cooperación con la Universidad Federal de Santa Catarina (Brasil), desarrolló una formulación robusta para la síntesis óptima de un mecanismo de cuatro barras generador de trayectoria [23]; y en cooperación con la Universidad Comunitaria de la Región de Chapecó (Brasil), obtuvo un método de optimización gráfica que determina la orientación ideal de un robot paralelo, con el fin de maximizar la rotación de su plataforma alrededor de un eje [24]. Adicionalmente, como parte de las labores de cooperación entre la Universidad Autónoma de Coahuila (México) y la Universidad de

Texas A&M (EE.UU.) se presenta el análisis de fuerza estática de una rueda Helse RSRR [25], que consiste en un mecanismo de dos grados de libertad que puede transformar una rueda circular en una rueda con múltiples extremidades.

También se han desarrollado algunos sistemas y prototipos para ser usados en la enseñanza del control. Al respecto, se puede citar el diseño y el control de un prototipo de bajo costo de un sistema *Ball and Plate* [28] como herramienta de recursos de aprendizaje, y el modelado y control de una grúa didáctica bi-riel [29]; realizados en la Universidad Pedagógica y Tecnológica de Colombia (Colombia). En esta misma línea, en la Universidad del Cauca (Colombia) se realizó el modelo dinámico y el control de una bicicleta robótica [27]; y en la Universidad Nacional de Colombia (Colombia) se desarrolló una interfaz de usuario inmersiva que, utilizando realidad aumentada, permite programar trayectorias para el robot ABB IRB 140, mediante el uso de un marcador cúbico y retroalimentación de información útil al usuario a través del dispositivo THC VIVE [26].

Teniendo en cuenta este panorama, en la *Sección I* se presentan algunos artículos cortos sobre trabajos que han sido desarrollados en distintas universidades latinoamericanas, con aplicaciones de la automática y la robótica en la agricultura, la educación o la industria. Luego, en la *Sección II*, en el formato de resumen extendido, se presentan algunos resultados preliminares de trabajos que, en el momento de su presentación en el congreso, se encontraban en desarrollo y que muestran algunas posibles aplicaciones en la industria y en el campo de la salud humana.

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Sección I

Artículos cortos

En esta sección se encuentran los artículos cortos que respaldan algunas de las ponencias realizadas en LACAR2019, en las que se presentaron resultados de proyectos de investigación y desarrollo tecnológico efectuados en distintas universidades de Latinoamérica.

Optimal energy transmission analysis through rotating machinery

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Abstract

Active Magnetic Bearings (AMB) are wide studied and applied nowadays, as for example in mining, petrol companies, power generator stations, etc. It is because this system improves efficiency in energy transmission as the consequence of controlled magnetic force over the shaft, which joins the source of the mechanical energy with the rotating machine (turbine, compressor, pump). Notwithstanding, shafts transmit not only rotating speed, also torque and quite advances of industry forced that shaft rotates at high speed values. Therefore, sensors and actuators must to be faster than this, but whether AMB cannot get an optimal position control, the electrical current, which produces the magnetic

field to achieve the controlled magnetic force, will provoke heat through the wires that contain it. For this reason, in this work is analyzed the impact of sensors and actuators that were based in nanostructures in order to get faster response time and robustness, while AMB system can find its desired position control. Furthermore, while the heat is reduced also from their magnets, the total efficiency can be transmitted in better percent than AMB without faster and robust sensors.

Keywords: Rotating machinery, bearings, Active Magnetic Bearings, heat transmission, nanostructures.

Introduction

Rotating machinery are frequently applied to transmit movement and energy, as it was given in electrical energy production, such as in intricate geographical areas, where there are fast flowing rivers (as for example, in Andes mountains rivers). Therefore, it is necessary energy conversion and transmission from mechanical energy to electrical energy by specific systems, such as turbines and electrical transformers. By other side, also there are applications, in which is very important to use rotating machines, because of mechanical movement transmission: mining, agriculture, fishing and every economic activity, which needs mechanical movement transmission. Nevertheless, while there is not good energy transmission in systems as it was described above, it will be necessary to use some mechanisms to reduce the produced heat in mechanical movement conveying that generally pollutes the environment.

To prepare this research, it was used a VARIAC (trademark for Variable Autotransformer) to get speed control in the rotor system that is composed by an alternating control (AC) engine that was coupled with a rotor, for which it is supported by an Active Magnetic Bearing (AMB) control. Also, owing to control algorithm strategies, it was studied some consequences (advantages and disadvantages) from nanostructures over the main control system, while energy transmission process goes through the other mechanical systems that is joined with the rotor [1], [2], [5].

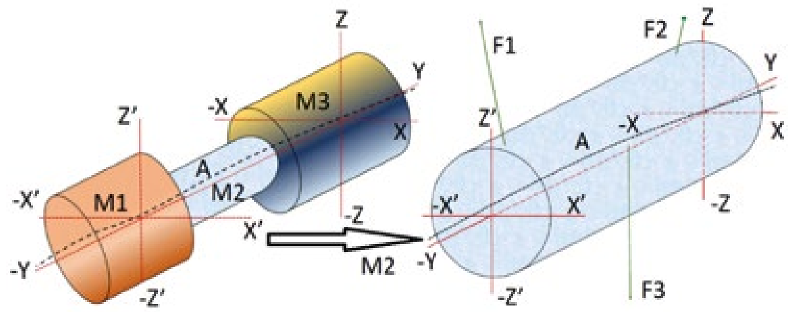
Furthermore, it was necessary to obtain a general mathematical model to describe energy transmission through the proposed system, in which the nonlinear model gave a good solution. The consequence effect to join sensors and actuators that were based in nanostructures support is the energy balance in all the mechanical system. It is because nanostructures robustness and fast response, which are the integration from nanosystem to macro system generate another good consequence: increase the efficiency of mechanical systems, because of reducing energy losses (heat) and in this context there would not be necessary so intense refrigeration complements [2], [3], [4], [5].

Problem and proposed methodological solution

In *Figure 1* is described a general system, such as the mechanical movement source, which is the motor (depicted by M_1); the machine that receives the movement could be a compressor, turbine, pump, etc. (depicted by M_3). Both situations joined by a rotor (depicted by M_2), for which represents the axis connection that cross 3 blocks. Furthermore, this figure represents Dynamic Forces Analysis over the rotor. Therefore, its mechanical physical movement can be described by Second Newton Law.

Figure 1

General rotor (shaft) scheme under the equilibrium of forces



Source: Own elaboration.

It means the equation 1, in which M_2 is mass of the rotor, F_g is its gravity force, F_R represents Reactions Forces and F_c is the inertial effect, because of circumferential movement around axis [5], that generalizes information of forces around the system that is composed complexly way joining M_1, M_2, M_3 and summarizes dynamic analysis over the shaft.

$$M_2 \frac{d^2y}{dt} = \gamma_y \frac{dy}{dt} + K_y y + F_g + F_R + F_C \qquad (1)$$

For which, it is necessary to remember the *y*, which is the selected coordinate to study the movement of the rotor. Also, every equation is in matrix analysis that means every solution in order to find parameters and coefficients that are in matrix solution too, as it is described in equations 2 and 3. The matrix that is composed for every stiffness coefficient is shown through equation three.

$$M = \begin{pmatrix} m & 0 & \cdots & 0 \\ 0 & m & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & m \end{pmatrix}_{nxn} \qquad (2)$$

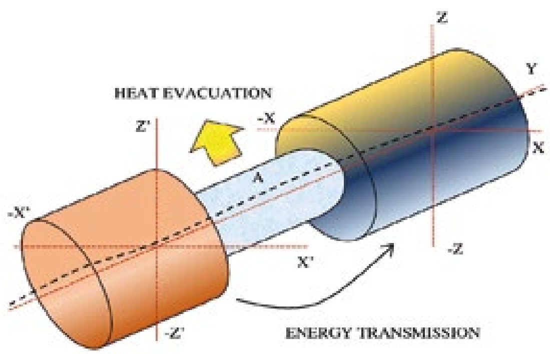
$$K_y = \begin{pmatrix} k_{y_1} & 0 & \cdots & 0 \\ 0 & k_{y_2} & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & k_{y_n} \end{pmatrix}_{nxn} \qquad (3)$$

By the other hand also, it is depicted the energy transmission in *Figure 2*, for which by the conservation of energy can be described mechanical movement transmission as in equation

1, as it was described above. Therefore, in *Figure 2* are represented the same blocks that do not need specific analysis of force to describe movement transmission. It means to correlate specific coefficients, such as the friction (as the function of heat) is explained better through the energy model, as it is given in equations 4 and 5. Notwithstanding, it is possible to verify the energetic model that can be achieved through a dynamic model, because of Lagrange.

Figure 2

General rotor (shaft) scheme under the energy transmission



Source: Own elaboration.

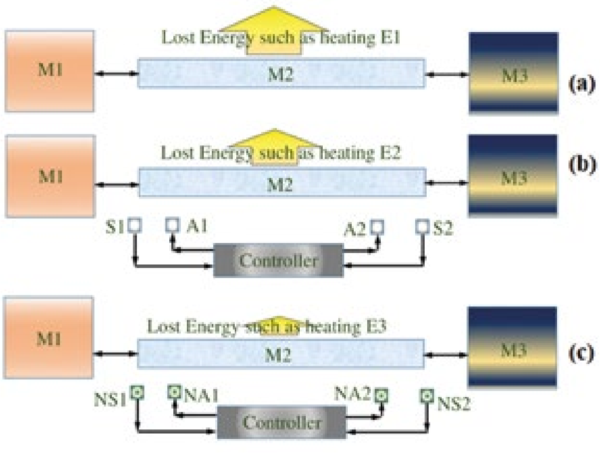
As a consequence, equation 4 describes energy balance over the shaft, for that *V* is its speed, and Z_f is the imbalance coefficient, due to energy transmission has losses.

$$\frac{M_2V^2}{2} + \frac{KY^2}{2} = Z_t \quad (4) \qquad \frac{d}{dt}\left(\frac{\partial Z}{\partial V}\right) + \frac{\partial Z}{\partial Y_i} = F_i \quad (5)$$

Otherwise, by Lagrange is obtained equation 5, in which F_i is the coefficient that helps to get losses approximation from the shaft. However, both equations that were described above are given for a component of its matrix form. Therefore, in this work it is proposed a high modulation from sensors to actuators, it means in *Figure 3* is represented the effect to improve a mechanic system by nanostructures. It means in *Figure 3a* is depicted a simple energy transmission among the mechanical systems, for which also must to be given lost energy, such as by the heat. How to avoid this? It could be reduced through many mechanisms of evacuating energy. However, it makes systems to be expensive without total reduction of the heat, because of the natural thermodynamic behavior of systems.

Figure 3

General rotor (shaft) scheme under the energy transmission and control



Source: Own elaboration.

Notwithstanding, while it is controlled by intelligent algorithms through sensors and actuators, the energy transmission enhances, but that transmission gets costing of the produced heat even AMB used over the rotor. It is because the energy transmitted through wires that produce electromagnetic field. Therefore, by faster sensors/actuators as it was proposed from sensors that were based in nanostructures (as in this research), the heat is reduced and movement transmission between rotating machines can get better efficiency. For this reason, it was necessary to quantify the heat that was produced over wires by Joule effect and the evacuated heat as the dependence of geometrical parameters and temperatures, as it was depicted in following equations. For this, *Q* is the heat evacuation due to friction, *T* is the temperature, *K* is the conductivity coefficient, *A* is cross sectional area to the heat flow, *U* is the excitation signal and K_p is the proportional gain of the thermal model.

$$\frac{dQ(t)}{dt} = KA\frac{dT}{dr} \quad (6) \qquad T_f = \frac{QL}{KA} + T_o \quad (7)$$

For which, the proposal solution is given by equation 7. It means that for steady state:

$$\frac{QL}{KA} = \Delta U K_p \quad (8) \qquad Q = (Q_1, Q_2, Q_3, \dots, Q_n)^T \quad (9)$$

And from which temperatures matrix:

$$T = (T_1, T_2, T_3, \dots, T_n)^T \quad (10)$$

By other side, it can be improved by control systems. Nevertheless, this is not totally good, due to in sophisticated systems that need fast and robust response, the controller (even so sophisticated) could be that it cannot reduce in total the heat transmission (it is depicted by *Figure 3b*). Therefore, what to do? It could be enhanced through faster sensors and actuators, as it is depicted in *Figure 3c*, it because sensors/actuators that were based in nanostructures.

The physical parameters identification and error analysis to get position control are given by a general system identification, as it is shown in equation 11, for a general expression of the rotor dynamic, in which I is the matrix of electrical current values for every component i. Furthermore, the stiffness coefficient K_y and electrical coefficient K_{IL}.

$$M_2 \frac{d^2y}{dt^2} = F_g + F_R + F_C + K_y y + K_{IL_i} I_i \qquad (11)$$

Such as it was described above, every component of last equation has matrix form. Also the polynomial solution gets the error as the dependence of desired signal in order to identify M_2, K_y and K_{IL} that are matrices as the equations 2 and 3, which were described in paragraphs above.

Equation 12 helps to evaluate the error matrix as the dependence of desired signal and the measured signal S in every instance n.

$$e(n)_y = d(n)_y - S(n)_y \tag{12}$$

$$S(n)_{y_i} = S(n)_i * [\boldsymbol{w}^T(n)_i \boldsymbol{X}(n)_i] \tag{13}$$

For every S is composed by adaptive weight coefficients that was correlated with the input signal (as measured or expected/simulated) X as it was described in equation 13. For this reason, the matrix of error is defined as:

$$e(n)_y = (e(n)_1, e(n)_2, e(n)_3, \dots, e(n)_m)^T \tag{14}$$

By other side, the general response *y(t)* correlated with *x(t)* and *u(t)* through a nonlinear function , it is because to look for the optimal trajectory and to get the best position control, as it is represented in equation 15.

$$y(t) = h(x(t), u(t), \theta) \tag{15}$$

$$J = (R_s - Y)^T (R_s - Y) + \Delta U^T R \Delta U \tag{16}$$

It means to solve the costing equation 16 by *J*, the expected trajectory *R*, in which this expected position is given by equation 17. And the optimal excitation signal in order to find the optimal response is given by equation 18.

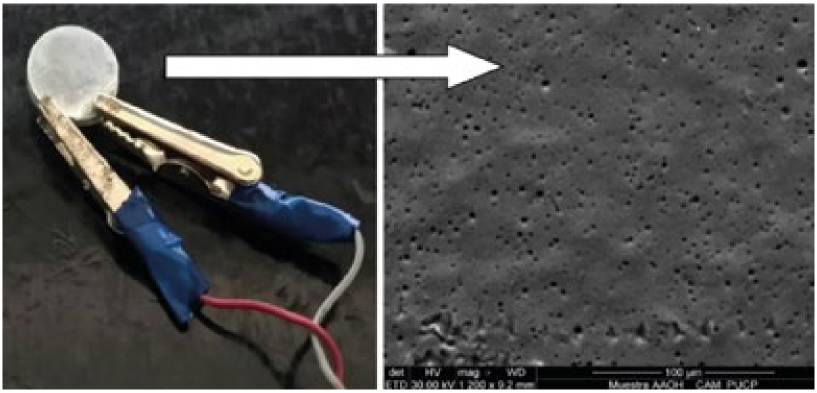
$$Y = FX(k_i) + \emptyset \Delta U \tag{17}$$

$$\Delta U = (\emptyset^T \emptyset + R)^{-1} \emptyset^T (R_s - FX(k_i)) \quad (18)$$

Anodic Aluminum Oxide (AAO) membranes have quite good mechanical, optical and chemical properties, hence, it helps to study designed sensors that were based in them. By other side, AAO membranes have fast response and robustness that means sensors that were based in this kind of membranes, which can achieve these characteristics. In *Figure 4* is shown an AAO membrane and, as indication of yellow raw, it is amplified in nanoscale view (from SEM PUCP) its porous [7].

Figure 4

The position sensor that was based in AAO membranes



Source: Own elaboration.

In *Figure 5* is depicted the setup to measure positions of the Active Magnetic Bearing (AMB), due to get its control, which is the machine used to evaluate the algorithms that were proposed in this research.

Figure 5

Experimental setup

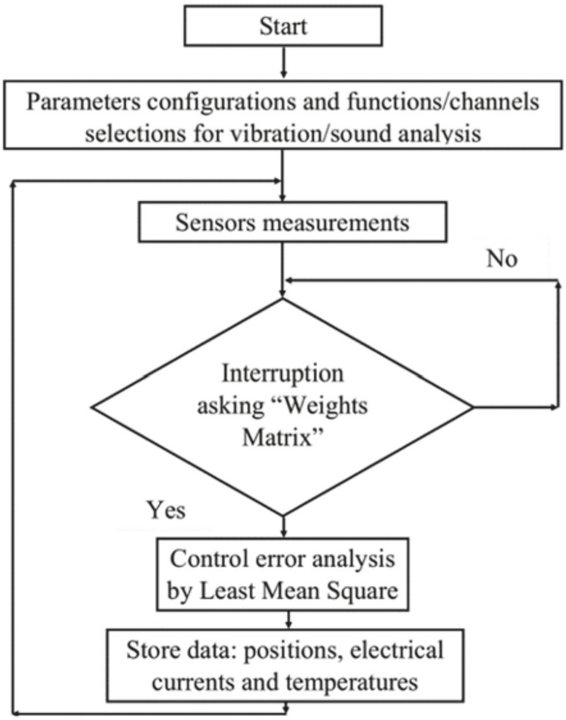
Source: Own elaboration.

1. Results

The position of the rotor (shaft) around its own axis was selected as physical variable in order to get a desired control, for which there were fixed four position sensors in opposite side to every electromagnet actuator, owing to capture its position as the reference from the shaft axis Y. However, through the position sensors that were based in nanostructure, it can be possible to correlate another important physical variables: Sound and vibration. In *Figure 6* is depicted as the flowchart, the summary of the procedure that was applied in this research. It starts from configuration parameters, measure sensors data: positions and temperatures. From this can be possible to find weights for adaptive algorithm in order to get better position control. In spite of the error signal (between desired and measured positions) can also get some predictions to optimal positions, but the energy needed to send over every electromagnet get losses, such as by the heat, but not because of friction. It is proposed by Joule effect. For this reason, it is necessary to measure temperatures and to estimate the heat evacuation from the AMB system, because of friction.

Figure 6

Flowchart to summarize steps sequence because to achieve the position control

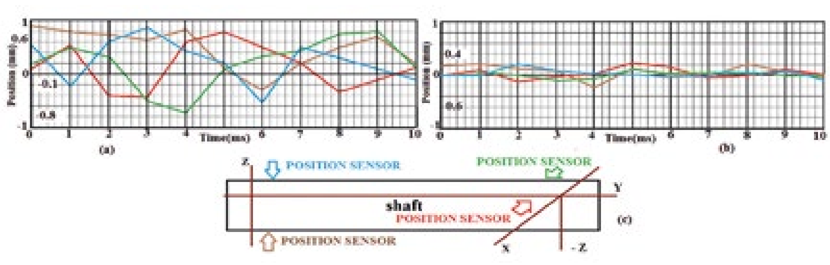


Source: Own elaboration.

As it was described above, in order to test the shaft movement transmission, it was activated only the hybrid electromagnet that was separated from the motor connector. Hence, in *Figure 7a* is depicted all control position, when it is measured by "sharp" position sensors, from which curves in color light blue, green, brown and red are the position that was captured by every position sensor.

Figure 7

The position control under the nanostructure effect



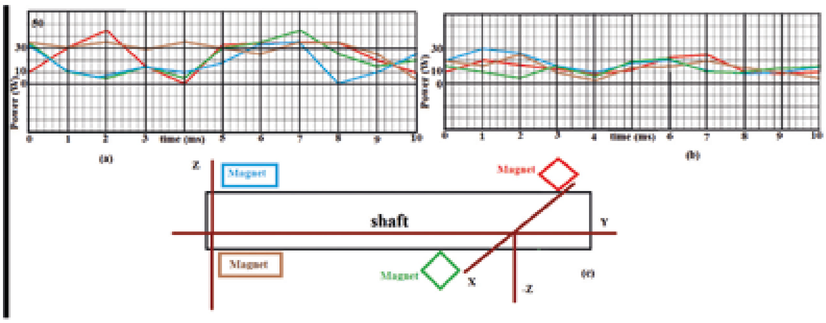
Source: Own elaboration.

It is shown that system is under control owing to the desired signal is 0 mm and the rotor must to be avoided to get imbalance rotation at 2 mm from its own axis. However, as it can be analyzed, there were found some overshoots that were achieved even the adaptive algorithm that was proposed. By other side, while it is changed every position sensor by sensors that were based in nanostructures, the control improves as it can be seen in *Figure 7b*. According to help visual explanation, *Figure 7c* shows a shaft setup for position sensors around it [6].

Finally, as it was detailed in paragraphs above: what is the consequence of heat that was produced by wires around hybrid magnets, which receive energy to produce the electromagnetic field (the main component to get equilibrium in AMB systems is depicted in *Figure 8c*)?

Figure 8

The energy evacuation as the nanostructure effect



Source: Own elaboration.

For this reason, *Figure 8a* shows power that was consumed, when there is not effect of sensors that were based in nanostructures, it is expected that no short response time makes the main control system could not get right response action. In otherwise, it can activate the hybrid actuators more time than it could be. So, does it mean that AMB cannot be in total efficient? To answer this question, it is necessary to get compromise between required range of work of the AMB, while it can be used to enhance movement transmission between rotating machines, the costing of the AMB in order to reduce the heat from lubrication of traditional mechanical bearings, but whether operating range of work can force the AMB according to increase energy that it needs to get operation, then of course, also this system can get losses by the heat.

This work shows a suggestion to solve that problematic by sensors that were based in nanostructures, due to their robustness, short response time can help in extreme conditions that traditional sensors cannot get. This is depicted in *Figure 8b,* due to reduced consumed power from AMB, because of nanostructure effect over mechatronic systems. According to help visual explanation, *Figure 8c* shows a shaft setup for position of magnets (hybrid between passive magnet with electro-magnet) around it, from which electrical current can increase its temperature without a controlled model that was based in nanostructures, as it is proposed in this research.

Discussion and conclusions

It was verified the good effect to use position sensors that were based in nanostructures, because of the wide range of work, robustness and fast response time as a consequence of nanosystems integrated in macro systems: the mechatronic systems. By other side, it was evaluated that AMB systems can enhance by better way their performance, when it is analyzed strategies to evacuate the heat that was not produced, because of friction among the rotor and bearings. In other words, the heat that was produced, because of the source of energy, which provides to the electromagnet actuators. Additionally, it is suggested to evaluate models that were proposed in this work with particular cases, such as M_3 (from figures 2 and 3 that were described above) could be a turbine, so it is suggested to analyze its dynamic, energetic and thermodynamic behavior as a consequence of nanostructures integration, as it is proposed in this research.

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Cyber-Physical Production Systems – Industry 4.0 Reference Cases to Latin America

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Abstract

Existing research of academia and industry reflects much higher expectations regarding the future of the factory. Several studies have demonstrated that modern automation focuses on the progress of the *New Information and Communications Technology* (NICT) and the emerging concepts of the *Internet of Things* (IoT). For example, *Cyber-Physical Systems* (CPS) for the industry are a crucial cause of converging technologies that can reply to the emerging globalized market demands. Indeed, applying CPS to manufacturing shows the advantages that gave birth to new terms as *Cyber-Physical Production Systems* (CPPS). Development platforms from the trend of automation, called the German *Industry 4.0* (I4.0), are based on CPPS. Both I4.0 and CPPS are often associated with other local concepts in Latin America (LA), e.g., *Agriculture 4.0* and the *Industrial Internet of Things* (IIoT), providing strong economic potential.

In LA, not all of the theory–referenced as the fourth industrial revolution–has been explored with rigor yet. Undoubtedly, promoting experiences and familiarizing researchers with these concepts should be the best way to address (substantially) new challenges in the LA industry. The main objective of this paper is to show a general analysis of the features of CPPS architecture that could be replicated in any production process. An adaptable CPPS would support the extension of industrialization, providing higher quality and more innovative products for the final consumer. The contextualization of the CPPS (the I4.0 foundation) offers a suitable opportunity to face the current challenges of the future factory. This work aims to address the futuristic landscape of industrial automation within the next years in LA by offering comparable international case studies.

Keywords: Cyber-Physical Systems, Cyber-Physical Production Systems, Industrial Internet of Things, Industry 4.0, Intelligent Manufacturing Systems.

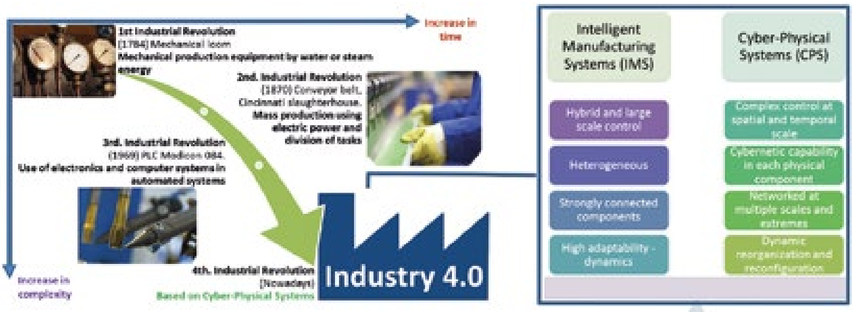
Introduction and motivation

Today in the research areas of academia and industry, there is a significant increase in results compared to expectations of future factory. Based on the progress of the *New Information and Communications Technology* (NICT) and emerging concepts of the *Internet of Things* (IoT), studies have demonstrated modern automation; a specific case of converging technologies is called *Cyber-Physical Systems* (CPS) and their applicability to respond to the emerging globalized market demands. Indeed, the use of CPS-manufacturing systems ongoing research seeking to demonstrate the advantages that these exposed [1]; namely, CPS conceived recent terms such as *Cyber-Physical Production Systems* (CPPS). Thereby, development platforms initiative called the –German– *Industry 4.0* (I4.0) is focused on CPPS, often related to other concepts for Latin America (LA) as *Agriculture 4.0* (extended by Brazil) and the *Industrial IoT* or IIoT (extended by the USA).

Fourth Industrial Revolution is a concept that is being developed, and which is generating a considerable impact on society and the economy [2], [3]. "Revolution" refers to a rapid and fundamental change, with significant transformations in a relatively short time. *First Industrial Revolution* was preceding the I4.0 (*Figure 1a*), occurred at the end of the eighteenth century, through the "acceleration" of mechanical production, which is based on water and steam; subsequently, the *Second Industrial Revolution* was generated in the early twentieth century, with the introduction of the conveyor belt and mass production. Stand out the names of the icons of this era, such as Henry Ford and Frederick Taylor; thus, the *Third Industrial Revolution* conceived by automation of production with electronics and computers. I4.0 has the relevant characteristics of *Intelligent Manufacturing Systems* (IMS) and CPS, as seen in *Figure 1b*, since become similar and high compatibility is projecting [1]. Emerging and prevailing in the future companies can widely benefit from the hallmarks of IMS approached from knowledge management. An example is the Plattform-i40 [4] where I4.0 and IIoT result from Germany, France, Italy, and other countries' cooperation, with open-access consultation. For this platform, I4.0 is not the computer that is the core technology, but rather the Internet. I4.0 means *"the intelligent networking of machines and processes for industry with the help of information and communication technology"* [4, pp.]. Other LA countries support smart manufacturing development by various initiatives (see Section 4.1).

Figure 1

The fourth industrial revolution based on CPS. Part a) I4.0 chronology. Part b) IMS vs. CPS



Source: Adapted from [9]

Theoretical Framework from the Literature Review

Several authors have defined the CPS. Particularly in [5], it refers to a new generation of systems with integrated computational and physical capabilities that can interact with humans through many new modalities. The ability to interact with and expand the capabilities of the physical world over computation, communication, and control, it is a crucial enabler for future technology developments. From processes and manufacturing, the CPS is the natural evolution of what corresponds to the plant floor giving rise to the CPPS, but still suffers from the integration/interaction with the business processes as required by I4.0 and that are present in the holonic approach. The state of the art of this paper is an extension lead of the work in [6].

Literature review: Principles of the Industry 4.0 Paradigm

Theories about I4.0 describe the development of called *smart factories*. Hehenberger *et al*. [7], explains the I4.0 paradigm implementation must be via NICT, and its integration should apply IIoT in manufacturing processes, which initially were considered as a network to promoted smart networks [8]. Moreover, Cruz *et al*. [6], shows I4.0 theoretical basis from nine technologies, such as: IoT, Big Data, autonomous robots, the 3D simulation, and others (artificial intelligence, 3D printing, autonomous vehicles, nano-materials, blockchain, biotechnologies, etc.) [9], [10]. Now, I4.0 focuses on CPS (*Fi-*

gure 1b), among others [11], [12]. CPSs are the integration of devices (computational type), networks, and physical processes; also, they are in charge of monitor and control of any process over feedback loops, which may include connectivity to the cloud. CPS technologies are based on old and new control theory concepts [12], but principally on still-evolve embedded systems [13]. Other paradigms are deployed as physical component entities (hardware) and cyber (software) converging towards the CPS, listed in [11], [14], [15].

The Cyber-Physical Systems Architecture to Manufacturing Adaptation

In [15], authors show a 5C architecture, which consists of five levels in a sequential workflow manner and illustrates how to construct a CPPS from the initial data acquisition through analytics to the final value creation. This work gives examples from the field of process, machine, or system-level monitoring. In a CPPS, approach the smart connection level (Level I) represents the physical space, Levels II-IV the "pure" cyberspace, while the configuration level (Level V) realizes the feedback from the cyberspace to the physical space. A description of the architecture levels is given in [15] and an application for intelligent machines given in [16]. This case study, on saw devices, shows an implementation of CPS in the manufacturing where all the necessary steps are covered, from acquiring data, processing the information, presenting to the users and supporting decision making. The case study shows the integration of the 5C architecture for processing and managing a fleet of CNC cutting machines, which are commonly used in manufacturing, but the current combination of the 5C CPS architecture is in its nascent stage. This architecture shows a way to implement CPS; we would have to explain about the process industry, for which we do not have until now reference.

Methodology to research and develop a CPPS Architecture

This proposal takes a holistic research methodology; therefore, even if there are multiple approaches to perceive a system (using tools to observe, learn, and understand what is perceived quantitatively and qualitatively). The ideas, rather than opposites, are considered complementary. Thus, this proposal is understood that research is a continuous and organized process which aims to meet some event (feature, process, or situation) and get answers to a need [17], which are established from the holistic approach, and given their complexity. These are hierarchical levels order low to high relevance: Perceptual, Apprehensive, Comprehensive, and Integrative [17]. The aim is describing an IMS control for production processes from the paradigm of CPS meets smart properties such as autonomy, flexibility, etc. One example is in [18], Cardin defines four aspects to be considered at the introduction of the CPPS into the industry, among them "The Learning Factory", which demands engineers and technicians trained to work in that environment. Additionally, the implementation of such systems needs a near Real-time IT-architecture in the cloud connected to a Real-time OT-architecture that controls the physical system.

Those aspects are not commonly available for Small and medium-sized enterprises (SMEs). Those are the critical constraints to the implementation of such systems. At the cloud, models of processes, products, and equipment are necessaries to describe, programming, supervise, and control the physical system. In [19], models for the description of the flows are shown as necessaries to perform the scheduling activities. Models of CPPS must describe the behavior of processes in several levels (plant-level execution, supervision) to have an integrated operation of the different CPPS working together to do production objectives. Those models are digital twins of physical processes and equipment. In practice, the new industry must ensure the convergence between IT / OT and the new concept of *Engineering Technology* that allows the application of digital twins, performing planning and scheduling activities in an efficient way and a better knowledge of the shop floor activities [20].

Reference Cases:
Selected Latin America I4.0 Implementations

In factories in LA, the incorporation of plant floor technologies, associated with the third industrial wave, has been low compared to Europe, North America, or Southeast Asia. The execution of manufacturing tasks is mostly associated with operators, and the programming of operations is given mainly by expertise that by the Engineering systems using information in real time. The application of the broad concept of intelligent manufacturing is *"… understood as a combination of software, hardware and/or mechanics, which should lead to optimization of manufacturing resulting in reduction of unnecessary labour and waste of resource …"* given in [21]. This concept can apply to the SMEs in LA, and the introduction of CPPS can help to improve the performance of those industries. The introduction of models (digital twins) for equipment, processes, and resources will allow advancement in the operation scheduling and the monitoring and evaluation of the execution, also considering economical aspects.

The main requirement to incorporate the concept of CPPS in SMEs, it is that SMEs decide to integrate the three levels of choice associated with the production process: economic viability of a production mode, logistics viability for a production order and the viability of execution on the technological infrastructure and human resources. Common models achieve the integration to the three levels of decision (digital twins), and the decision process established under the concept of feedback systems for the CPPS. Associated with the decision of the company to address the change for the incorporation of the I4.0 concept at the enterprise, it is necessary the presence of experts that help the industry in the management of the ideas and the construction of digital twins and the implantation or adequacy of decision-making systems.

International countries' initiatives regarding the I4.0 paradigm

The World Economic Forum (WEF) is a relevant international organization for public-private cooperation engages I4.0 and involves other social strategies. WEF reports crucial recommendations about smart factory initiatives around the world. *Table 1* indicates I4.0 some countries' initiatives, and many of them usually come from the original German I4.0 or WFE [22]. [21], [22]. In the future cases of LA I4.0 implementations, it should be necessary to have a look at the relevant results in advanced countries, as well as those, which already have obtained effects.

Table 1

Relevant I4.0 initiatives, platforms and tools for the implementation of I4.0

Country	Name	Description	URL source
Brazil	Special survey of the CNI	An online data that identified the ten digital technologies for I4.0 in the Brazilian industry	www.portaldaindustria.com.br/statistics/special-survey-industry-4-0
	Agriculture 4.0	Vision 2014-2034: the future of the technological development of Brazilian agriculture	www.embrapa.br
	Be Brasil	Start-up ecosystem of I4.0 Brazilian innovation	www.bebrasil.com.br

Country	Name	Description	URL source
Colombia	INNpulsa (Min. Comercio)	Colombian business growth management unit leading I4.0 projects national companies	www.innpulsa-colombia.com
	Ruta N	Medellin innovation and business center with I4.0 cluster from WEF	www.rutanmedellin.org/es/cuarta-revolucion-industrial
	UNLab 4.0, Universidad Nacional	Laboratory focused on reducing human capital inequality in the 4th Industrial Revolution	inticolombia.unal.edu.co/proyectos.html
China	Made in China 2025	Initiative to upgrade Chinese industry as a direct inspiration from Germany I4.0	english.gov.cn/2016special/madeinchina2025/
France	Future Alliance's website	150 more French real-world examples of I4.0 and future projects	exemples-aif.industrie-dufutur.org
Germany	Plattform Industrie 4.0	Six working groups of German entities (BITKOM, VDMA, ZVEI, etc.) to advice I4.0	www.plattform-i40.de
	Digital Self-assessment	An online instrument with 33 questions with initial differentiation of the sector applicability	i40-self-assessment.pwc.de
	IMPULS – I4.0 Readiness	Online tool to companies I4.0 diagnostics, by the division of six components dimensions	www.industrie40-readiness.de

Country	Name	Description	URL source
Italy	I4.0 Plan (Impresa 4.0)	Piano 4.0 supports Italian companies with a wide range of measures to I4.0	www.mise.gov.it/index.php/it/industria40
Spain	Industria conectada 4.0	Platform to promote the digital transformation of the Spanish industry	www.industriaconectada40.gob.es
	HADA–an auto diagnostic tool	An online instrument as advanced digital self-diagnosis of I4.0 implementation in SMEs	hada.industriaconectada40.gob.es/hada
Hungary	Eureka Intro4.0	Project platform that integrates Hungarian academic/industrial partners to I4.0	www.eurekanetwork.org/project/id/10389
Mexico	Crafting the Future	Online vision map of the I4.0 for production based on collaboration ecosystems	www.promexico.mx/documentos/mapas-de-ruta/industry-4.0-mexico.pdf
United Kingdom	Autodesk questionnaire	An online instrument driven by FOBMI to the limitation of the scope for I4.0 in UK	fomt.autodesk.co.uk/en/tool/fomt/tool/
USA	IoT consortium	Program to transform business/society by IIoT	www.iiconsortium.org

Source: Own elaboration.

Medellín as a Centre for the Fourth Industrial Revolution from Colombia

The case for Colombia, Medellín is its second central city. In 2013, beating the other finalists New York and Tel Aviv, Medellín honored with a *City of the Year* award, because of its innovative initiatives as well as the mobility, environmental sustainability [22]. Medellín's economic dynamics is focused on a diversity of aspects that are a focus in several clusters: i) fashion and advanced manufacturing, ii) sustainable energy iii) sustainable habitat; iv) business tourism; v) Medellín health city, vi) digital business and vii) cluster of coffee. Different entities are part of the innovation ecosystem of the city that is born from the strategic plan of science, technology, and innovation of Medellín 2011-2021, based on the 22@Project of Barcelona, which focuses the efforts on promoting innovation. Public organisms, as the "*Corporación Ruta N*" generates innovations in the city, together with companies, universities, the State, and society to a social transformation [22].

This corporation has achieved several milestones such as the creation of a business landing to improve the relationship of companies, and promotion the technological change to the Smart Manufacturing by financing projects in I4.0 and IoT [23]. The *Capital N program* founds projects for new entrepreneurship, administer public funds for innovation projects, in technology and markets for the search for business opportunities. Examples of the I4.0 tests are given by other enterprises in Antioquia (Department of Colombia): the project "Transformación digital" for Invesa, (2018), Pintuco: "Seguimiento energético de la Producción" (2017-2018), acting as consulting SIMAC S.A.S, and others. In 2018, the WEF selected Medellín to create the first the *Centre for the Fourth Industrial Revolution Network (C4IR)*, to accelerate the benefits and minimize the risks of emerging technology. [21]. This center aims to include institutions advancing public-private cooperation on the governance of emerging technologies. It joins the centers in Israel and Arab Emirates C4IR networks that focuses on nine areas of interest: i) artificial intelligence and machine learning, ii) IoT, robotics, and smart cities, iii) blockchain and distributed ledger technology, iv) autonomous and urban mobility, v) drones and tomorrow's airspace, vi) precision medicine, vii) digital trade, viii) fourth industrial revolution for the earth, and ix) data policy.

Discussion, Conclusion and Future Work

The industry of LA underlies the multinationals, and if it takes I4.0 as a paradigm, it will be reflected sooner rather than later. In the automotive sectors, as well as in agro-industry and critical systems such as water, gas, oil, electricity, and transport, they are candidates to be digital leaders. Quickly multinationals establish vital technologies in I4.0 by CPPS mentioned above, but in SMEs, there is a criticism derived from the associated costs. As a reflection, in the case of LA, the transitions of the labor force, in an era of automation, will be strongly affected by the cost of labor that is relatively low versus adequacy, training in the automation process for its costs and time required. Perhaps our most important barrier is that we do not think about ourselves and, on the contrary, we think about what multinationals do. In any scenario, having a human capital with the required capabilities is a challenge in any country.

Thus, as a further design, a CPPS architecture for LA should support communication between people, machines, and products more efficiently, since their technology may allow data acquisition processes for more autonomous, but limited control [20]. It remains indispensable for specific tasks to interact with humans (for example, maintenance), this will be achieved through adaptable (efficient and reconfigurable) interfaces and IMS. These needs require more decentralized applications supported by IIoT, where CPPS work comfortably, although typical hierarchical control levels, including programmable logic controllers (PLCs), prevail in the industry [24]. The application of I4.0 paradigm in LA implies the adaptation of elements of monitoring and supervision in a non-fully automated floor plant, and the need for training of technical personnel and engineers in modeling techniques, control of integral supervision, analytical data that are novel, both in LA and in the rest of the world [18].

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Type II fuzzy logic controller for a liquid level system

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Abstract

This paper deals with the design and implementation of a type II logic fuzzy controller. Thus, using artificial intelligence (AI) techniques for better performance over a classical PID controller. The type II logic fuzzy controller was designed using the Fuzzy Type 2 toolbox using the Matlab professional software. The results through the prototype of level control allowed identifying the advantages of the fuzzy logic controllers type II with respect to its predecessor: the type I fuzzy logic controllers. This was verified using the dynamic response performance parameters as the maximum overshoot and the setting time.

Keywords: Fuzzy logic controller, type II fuzzy logic controller, level control system.

Introduction

Fuzzy logic systems have been applied successfully to a wide range of problems in different applications. One of these types of applications refers to the use of fuzzy logic systems for the modeling and approximation of fuzzy inference systems. This is used to model human knowledge or for linear or non-linear approaches. However, the existence of uncertainties and the lack of information in many global problems make it difficult to model such problems using only expert knowledge. Although, type I fuzzy logic systems are the best-known model of fuzzy logic they have received attention for decades. The advance in the research of fuzzy sets and type II fuzzy systems and its better performance on systems of type I fuzzy logic controllers, caused that they motivated many researches to solve problems and in this way to control different systems [1-12].

A prototype was used in this work to know the advances of these investigations and the benefits of this type of controller. For which the results were verified and contribute to the development and implementation of this type of control strategy.

Control system of a liquid level

The process used as a test bench for this work is shown in *Figure 1*. The system has two tanks of rectangular shape, which the lower tank will have as a function to store the fluid so that by means of the pumping machine be pumped to the upper tank. The fluid level in the upper tank is measured by differential pressure sensor. The control action is carried out through a solenoid valve, which will have the function of controlling the amount of liquid that flows through the pipe in order to regulate the flow of the fluid.

Figure 1

Level bench for liquids

Source: Prepared by the authors

Fuzzy logic controller (FLC) design

The fuzzy logic controller design of the type I controller will first be designed to establish the parameters of the type II fuzzy controller, and in this way, show the differences between them. The development of a fuzzy logic controllers was done under the structure of a PD controller; therefore, it can be established that the controller will depend on two input linguistic variables. In this way, part P will be under the signal that occurs from the difference in closed loop between the reference value with respect to the measured value (Error), and part D will be established from the difference between (current error) with respect to (previous error) calling this as the error delta (D.Error).

Input variables

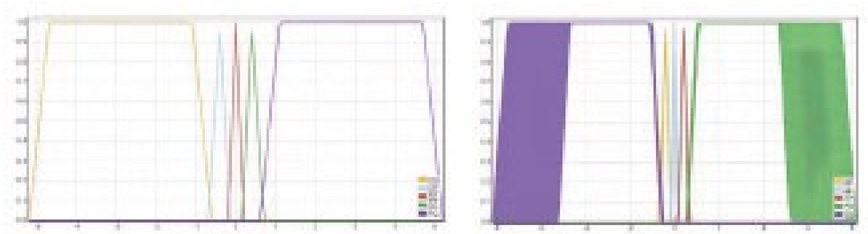
For the universe of discourse of type I and type II fuzzy input drivers, it will depend on two variables that are named (Error) and (D. Error). For both variables, trapezoidal and triangular membership functions will be used, given that they have a low mathematical computational cost with respect to the other membership functions.

Error variable

The universe of discourse of the input variable (Error) for both type I fuzzy and type II fuzzy, will have five membership functions: large negative (NG), small negative (NP), zero (ZE), small positive (PP) and large positive (PG). *Figures 2.a* and *2.b* show the membership functions in the universe of discourse for the error variable for type I and type II fuzzy, respectively.

Figure 2

a) Universe of the Error variable for the type I fuzzy; b) Universe of the Error variable for the type II fuzzy



a) b)

Source: Prepared by the authors

D.Error variable

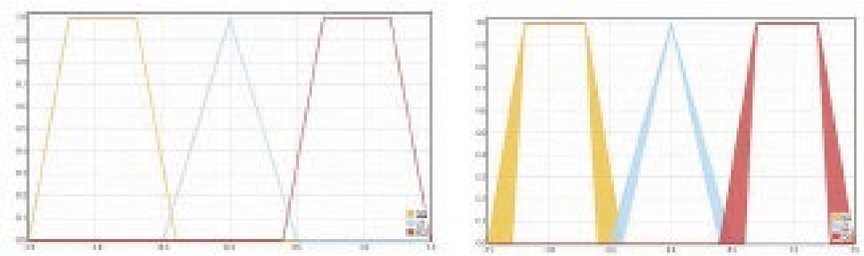
The universe of discourse of the input variable (D.Error) for type I fuzzy as well as type II fuzzy, will have 3 membership functions: large negative (NG), zero (ZE), and large positive (PG). *Figures 3.a* and *3.b* show the membership functions in the speech universe for the variable (D.Error) for type I and type II, respectively. This parameter will serve to a large extent to verify that the measurement system is always in good working order since when presenting a fault, the difference of the error will be significant, in the same way when there is a sudden change in its level measurement due to disturbances, etc.

Output variable

For the universe of discourse of the type I and type I fuzzy logic controllers, it will depend on a single variable that is called controlled variable. For both control strategies, the Sugeno method is used since this avoids a higher computational cost, which is essential in the control scope at the time of implementation.

Figure 3

a) Universe of the D.ERROR of the type I fuzzy; b) Universe of the D.ERROR of the type II fuzzy



a) b)

Source: Prepared by the authors

Controlled variable

The universe of speech of the output variable (controlled variable) for type I fuzzy and type II fuzzy, will have 5 membership functions: large negative (NG), small negative (NP), zero (Z), small positive (PP) and large positive (PG). For these functions, functions of constant type will be used where only one value is assigned, which for the purposes of the implemented system will be the value of the PWM type signal since with this the control action on the solenoid valve can be exercised. *Table 1* and *Table 2* record the data of the parameters of the delimitations of each function for fuzzy sets.

Table 1

Parameters of type I fuzzy output functions

CONTROL	
FUNCTION	**VALUE**
NG	0
NP	30
Z	82.1
PP	150
PG	255

Source: Prepared by the authors

Table 2

Parameters of type II fuzzy output functions

CONTROL			
FUNCTION	**TYPE O FUNCTION**		**PARAMETERS**
NG	SHARP		0
NP	INTERVAL	UPPER	30
		LOWER	10

CONTROL			
FUNCTION	**TYPE O FUNCTION**		**PARAMETERS**
Z	SHARP		82.1
PP	INTERVAL	UPPER	240
		LOWER	150
PG	SHARP		255

Source: Prepared by the authors

Rule base

In *Table 3* are the rules which were designed so that the process does not present overshoot, in the same way that the response is rapid and that in stationary state exerts its control action.

Table 3

Rules for type I and type II fuzzy control systems

IF (ERROR)	AND (ERROR)	THEN
PG	ZE	PG
PG	NG	PG
PG	PG	PG
PP	ZE	PP
PP	NG	PG
PP	PG	NP
ZE	ZE	ZE
ZE	NG	PP

IF (ERROR)	AND (ERROR)	THEN
ZE	PG	NP
NP	ZE	NP
NP	NG	NP
NP	PG	NG
NG	ZE	NG
NG	NG	NG
NG	PG	NG

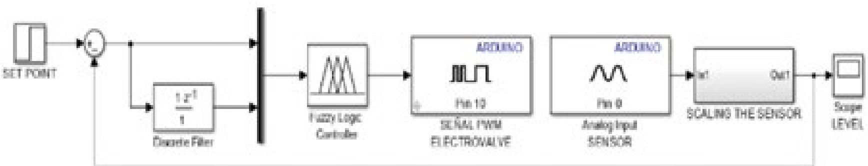
Source: Prepared by the authors

Results

For the implementation of the fuzzy logic controllers, the block diagrams of *Figure 4* and *Figure 5* were implemented through the Simulink-Matlab software.

Figure 4

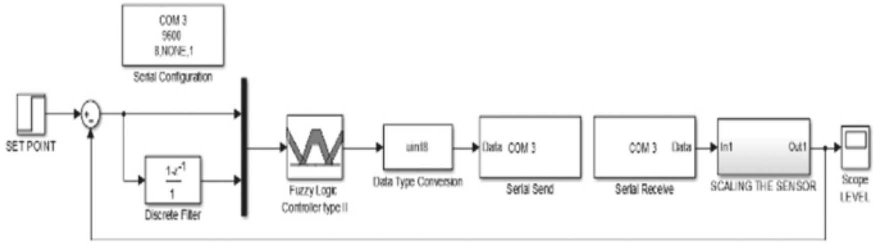
Fuzzy controller diagram of the type I fuzzy



Source: Prepared by the authors

Figure 5

Fuzzy controller diagram of the type II fuzzy



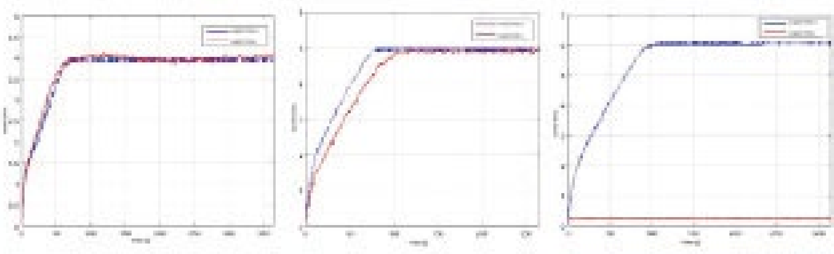
Source: Prepared by the authors

Change in reference level value

To validate the robustness of the control systems designed in this work, the control actions will be at different reference level points. The cases will be raised a unit of higher level and a lower one, that is to say for a reference level of 6 cm and 4 cm. In *Figure 6.c*, the fuzzy controller type I response (red line) for a reference level of 6 cm, this does not exert its control action given that the desired value is not contemplated within the universe of discourse having clear fuzzy sets do not have a margin of tolerance in front of certain uncertainties that could occur, otherwise with type II fuzzy control strategy (blue line) given that it exerts its control action in the level of referral required for the system. *Figure 6.b*, presents a very good transient stage, highlighting in this the reduction of the stabilization time by fuzzy technique type II (*blue line*) with respect to fuzzy type I. *Figure 6.a* shows the performance of the control systems for a reference level of 4, they present a very good transient stage, highlighting in this the reduction of the stabilization time using the type II fuzzy technique (*blue line*) with respect to the type I fuzzy since this presents a slight over-impulse originating a kind of oscillation or wave in its signal for the required reference level.

Figure 6

Response of fuzzy logic controllers for reference levels



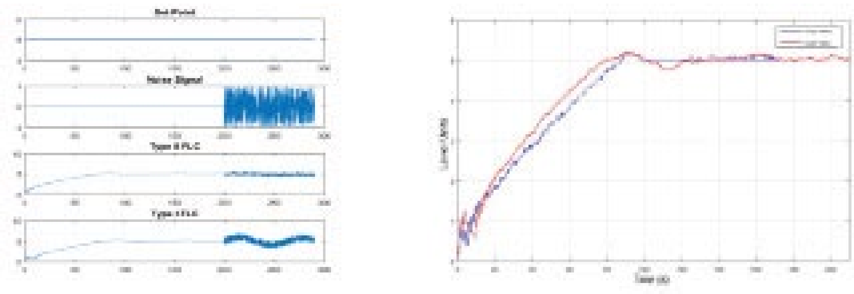
a) b) c)

Source: Prepared by the authors

As a final validation of the fuzzy control systems, two additional cases are made. The first case adding a noise signal to its loops that will have the function of simulating a disturbance outside the measurement system, the second case adding a delay block to their control loops, in order to establish the differences in response in fuzzy type I and type II technique, respectively, and observe their robustness in the face of certain inaccuracies. As can be seen in *Figures 7a* case 1 and *7b* case 2, the fuzzy type II controller performs a quick corrective action maintaining its permanence in the stable state being a better response.

Figure 7

a. Response with noise signal; b. Response with delay



a) b)

Source: Prepared by the authors

Discussion

Regarding its counterpart, the type I fuzzy controller, can be established an advantage given that having sets with uncertainty trace can be used by the controller designer to achieve a greater range of control operation in the units of level, where can also simulate uncertainties or inconveniences that could arise in a real scenario. This shows a great behavior of type II fuzzy controller versus type I fuzzy controller where the main advantage observed in *Figures 7a* and *7b* is a good performance of the control system against uncertainties, in addition to a faster response to achieve the setting time (Ts) without presenting overshoot (Mp).

Table 4

Comparisons to of the responses

REFERENCE LEVEL (LEVEL UNITS)	TYPE ONE FUZZY		TYPE TWO FUZZY	
	Ts	Mp	Ts	Mp
5	105s		80s	0%
6	NO CONTROL		95s	
4	92s	0%	67s	0%

Source: Prepared by the authors

For the control loops with the presence of a delay in front of the fuzzy controllers, the difference between the two can be observed, obtaining as a result a much greater affectation in type I fuzzy technique with respect to type II fuzzy, it is valid to make this clarification, since that in normal conditions for this same reference level its behavior does not present either overshoot or oscillations at steady state (*Figure 6.b*).

Conclusions

The implementation of the fuzzy logic controllers of the level control prototype, it is the type II fuzzy controller presents the best response. Likewise, thanks to its second membership function type II fuzzy systems present a great advantage because they can consider the design ranges for uncertainties or events that could occur. In the methodology for the development of type II fuzzy controllers, the type to be implemented is prioritized. Facilitating the calculation of the response result for the control system since the computational cost will be much lower through the selection of Sugeno. Because this will not be done by reducing the type of fuzzy sets of type II to type I, this being the main difference with it. And, the improvement in the response of the control system to uncertainties.

The fuzzy type II controller obtained better performance conditions against all possible scenarios, showing as results a great robustness by this control strategy to noise signals, level reference changes, delays in the response of the sensed signal in front of to the fuzzy type I controller.

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Lane Detection and Trajectory Generation System

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Abstract

This paper presents the development of a perception system that enables an Ackermann-type autonomous vehicle to move through urban environments using control commands based on short-term trajectory planning. We propose a lane detection and keeping system based on computer vision techniques that are computationally efficient. Also, a Kalman filter-based estimation module was added to gain robustness against illumination changes and shadows. Additionally, the simulation and control of the "Autónomo Uno" robot gave good results following the steering commands to keep the position. In the simulation, the controllers had some slight

noise problems, but the robot executed the given steering commands and it moved following the road. This behavior was also seen in the physical implementation.

Keywords: Autonomous vehicle, computer vision, lane detection, lane keeping, Ackermann kinematic model.

Related work, motivation and objective

Since the late 20th century there have been studies about systems focused on lowering the amount of lives lost due to traffic accidents, improving road safety and increase the autonomy of the vehicle. These systems are known as Advance Driving Assistance Systems (ADAS). One of the main features of ADAS is lane detection and tracking, which it is a task where real-time processing is most crucial, since this and the steering actuation system are the ones controlling where the vehicle is headed with respect to the vehicle's position in the lane and its surroundings.

In the study presented by Narote et. al [1], is shown that there have been different advances on the development of this techniques. On 2015 Son et. al [2] present different modules working together to do lane detection, some of these modules include color invariant lane detection when exposed to illumination changes, adaptive region of interest (ROI) based on the vanishing point, Canny edge detection, and lane grouping using minimum squares. Using these modules on a simulated environment, they got a fast and powerful result for real-time application under different weather and lighting conditions. But roads with cracks and blurred lane markings were this system's weak spots.

A year later, Madrid and Hurtik [3] presented a low-cost warning departure system for vehicles, which is efficient and affordable for most people. They use the Hough transform for line detection together with a fuzzy image representation, which gave better results than the standard Hough transform with the Sobel operator. It also presented a reliable and accurate response to real-time processing. This system had difficulties during the night and when white vehicles enter the scene.

Mammeri et al. [4] on 2016 presented an internal computing system that finds the lane markings and passes them to the driver. For the line detection, they used Probabilistic Progressive Hough Transform, ROIs through MSER blobs were also used, which are then refined using a three-stage algorithm. Using the MSER results, the lane colors (white and yellow) are identified on the HSV color-space and Kalman filtering is used to follow both lane lines. This system is limited at night due to the road lighting and traffic conditions.

On the other hand, there has been little interest in Colombia to develop these kinds of technologies due to the economic and infrastructure difficulties present in the country. This lack of interest can be seen on the low adoption and acceptance of using technologies associated with renewable energies in the transport sector such as electric autonomous vehicles. Nevertheless, studies and work done in this area in world powers give a hopeful future that could bring many benefits to the Colombian territory [5].

These benefits are the main motivation to create a perception system for vehicles that facilitates lane detection and trajectory generation on urban environments. Hoping that the creation of software for platforms that want to develop autonomous vehicles, will promote research and development on this area in a national level.

Methods

This work was developed in three stages, first the Lane Detection system, second the Trajectory Generation system and finally the system was tested in the Autónomo Uno robot and, at the same time, in a simulation environment in Gazebo. For the development of the Lane Detection system, we mainly used videos [6] that were converted from mp4 format, to rosbag so they could be better integrated with ROS, since this environment allows easier integration with robot control hardware.

Perspective transform was used to create the bird's eye view (BEV) of the road, based on a fixed ROI in order to avoid the vanishing point effect. Besides, the BEV view provides better information of the road which it helps to create a more accurate lane model. Using this transformation, it is easier to find the center of the lane and the error for the car to steer, so it can stay in the center of the lane. We predefined the ROI, since our own automatic ROI finder was too inefficient working at an average of 2 FPS on a 30 FPS video. Once the BEV is obtained, the following computer vision techniques were used to enhance the lane markings and filter unwanted data: grayscale conversion and vertical Haar-like feature filter [7].

After, the image is divided into two parts, one for each of the lane markings. Then, each image's histogram gets equalized and a median filter is applied along with pixel-wise gamma correction using γ=20. These steps are done in order to enhance the brighter colors present on the lane markings, so it is easier to apply a threshold to binarize the image. Furthermore, image binary thresholding was performed on the value range from 240 to 250, where pixel values go from 0 or black to 255 or white, greater values were not selected due to included noise.

The Lane model is created by passing a set of sliding windows vertically through each of the lane markings and finding a set of centroids that describe each marking. The parameters used for the sliding windows are their height (W_h), width (W_w), number of windows (N_w) and horizontal starting point of search (S_h). The $W_{w,}$ N_w and S_h are defined by us, but the height of each window is found dividing the image height (h) by N_w. The centroids for each marking were found by averaging the values of the x coordinates for the with pixels in the window's area. The search process is repeated until N_w windows have been placed.

Kalman Filtering [8] was used to either filter the changes on the x coordinate of each centroid or to predict the position if no white pixels are found due to broken lines. Also, Kalman filtering is not applied on the y coordinate since it increases by a fixed known value W_h on each iteration. Finally, the center line was found by computing the difference between centroids of each lane model.

The Trajectory Generation system is based on the middle line provided by the lane detection system. First, two points of the middle line are selected for the steering vector, then the steering angle is calculated as shown in eq. 1. Where pt_1 is the closest point to the car and pt_2 the sixth point of the middle line, also the index *x* and *y* indicate the respective coordinates of the points.

$$\theta = arcsin\left(\frac{pt_{1x} - pt_{2x}}{\sqrt{(pt_{2y} - pt_{1y})^2 + (pt_{2x} - pt_{1x})^2}}\right) \qquad (1)$$

The steering angle is used along with the selected points to create the steering vector. This vector describes the short-term trajectory that the vehicle needs to follow in order to stay in the middle of its lane. Furthermore, the steering angle is used to compute the inverse kinematics of the mobile robot, thus the Ackermann-type vehicle is able to move the steering wheels to perform the trajectory.

Finally, the system was integrated with the physical platform Autónomo Uno robot, also with the simulated environment using ROS along with Gazebo. The inverse kinematics of mobile robots [9] were used to control the Ackermann-type vehicle, in addition, a Proportional-Integral (PI) controller system was added to control the response given by the vehicle while it follows the steering vector provided by the lane detection system.

One of the main inputs to our simulation system is the robot's heading, which is provided by the vision-based trajectory planning module. This heading value is translated into steer commands for each of the front wheels using the instantaneous center of rotation's (ICR) distance and the ICR's angle, which are provided by the inverse kinematics. The ICR distance is computed as shown in the eq 2.

$$ICR_{distance} = \frac{length}{tan\ (\theta)} \quad (2)$$

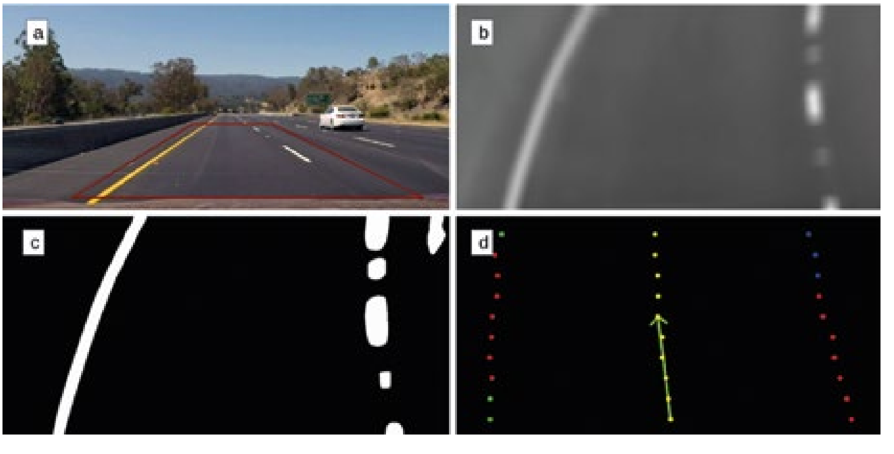
Results

The results of the Lane Detection system and Trajectory Generation system can be observed on *Figure 1*. Where on figure 1a the ROI we defined can be seen delimited in red. Then, on *Figure 1b*, we can see the BEV view and the lane markings after the filtering. The final process to enhance the lane was performed and the result can be seen on *Figure 1c*. After, the sliding windows step is done and the centroid-based lane model is created, see *Figure 1d*, where the centroids in red are those detected by the sliding windows, but the ones in blue or green are the ones predicted by the Kalman filter, since the observation was not confident enough.

The center line model can be observed on figure 1d, along with the steering vector. The behavior of this steering vector can be tuned by choosing a different point as pt_2. We found that selecting pt_2 too close to the car, makes the system too sensitive to variations in the centroid's x coordinate. Also, by choosing pt_2 closest to the top side of the image reduces its sensitivity. The sixth point was chosen because it gave stability and good angle representation in both cases: straight and curve roads.

Figure 1

a. Manual ROI defined, b. Filtered perspective transform of a road curve, c. Binary image after thresholding, d. Lane centroids and steering vector



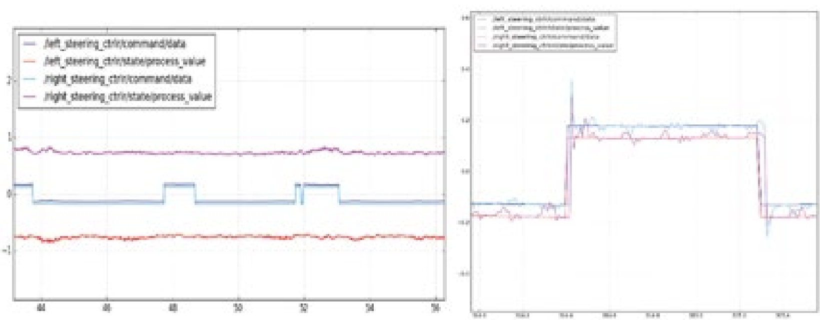
Source: Own elaboration

The Ackermann Kinematics model defined in [9] is computed locally in the Autónomo Uno robot, using the two main micro controllers installed. The first one is the Raspberry Pi 3 B+, that allows communication with a main computer in order to receive control commands. The second is an Arduino DUE, that controls two different types of motors used for traction and direction respectively. Also, each motor has its own built-in PID controller that manages its respective behavior.

On the other hand, the Ackermann Kinematics model needed for the Gazebo simulation environment are computed on the main computer. Also, the dynamics involved in the environment requires a controller module, see *Figure 2* (left). Here the red and pink signals are respectively the front wheels response to the steer angle.

Figure 2

Left, Initial response state of the system without controller. Right, Ackermann system response with PI controller

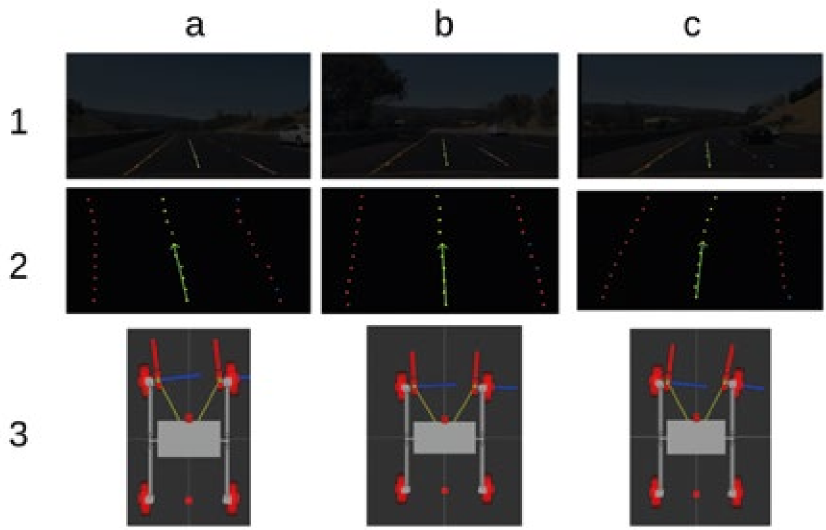


Source: Own elaboration

Therefore, a PI controller was created using the Ziegler-Nichols tuning method [10] for the steering and velocity of the wheels. Even though the signals with the controller have noise, *Figure 2* (right), the system manages to follow the setpoint of the steering angle. This behavior was seen on the simulation environment and in the physical platform. On *Figure 3*, the system's response is shown for three principal cases, turn left, go straight and turn right.

Figure 3

Column a. System behavior for left-curved road, Column b. System behavior for straight road, Column c. System behavior for right-curved road



Source: Own elaboration

Discussion and conclusion

We were able to create a lane keeping algorithm for autonomous vehicles based on traditional computer vision techniques, that is robust to illumination changes and manages to detect and track lanes under different conditions such as: lane markings with two different colors (yellow and white), lane markings exposed to direct sunlight, shadows and transitions between asphalts of different color. Also, the system can react to the two main lane types, straight and curved. Furthermore, the system controls the vehicle's heading, based on a short-term trajectory generation and the Ackermann Kinematic model so the vehicle stays in the center of the lane, which is an added capability compared to Lane Departure warning systems presented in [2], [3] and [4].

We also highlight the use of sliding windows versus the Hough Line transform and its variants used in [2], [3] and [4] since we are able to model with a fixed number of sliding windows each lane marking by representing them as series of points. The main problem with the use of the Hough Line Transform is the detection of only straight lines. Thus, to detect curved features the system needs to either detect small segments of the curved line and piece them together to create the lane model, or it needs to do a rough approximation of a curve with a straight line, which could not be an optimal model.

For future work, we recommend doing a comparative analysis between our method and the ones presented on previous work, focused on the computational cost and real-time performance. Also, given the current trend on the Computer Vision field, it would be interesting to see the Deep Learning-based approaches to both the perception and decision modules.

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Design and implementation of a PID controller for a didactic pneumatic levitation system monitored by smartphone

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Abstract

This work presents a prototype of a vertical pneumatic levitator as an educational resource for encouraging control learning. The objective is to control the position of a ball inside of a pipe, by an airflow. This paper shows a learning experience developed in an undergraduate course, where students construct the prototype plant, obtain its mathematical model, and design a digital PID controller. In this exercise, students work in a team in a Project-Based Learning experience focused on comparing the behavior of a simulation model to the actual plant. For observing changes in the ball position inside the pipe when the user changes the set point, the team develops an App in Android that facilitates the interaction with the prototype.

Keywords: Pneumatic levitator; digital PID; App Android; Step-test.

Introduction

The suspension of a body in the air is a phenomenon known as levitation; this suspension can be achieved through a pushing force by different means so that that levitation can be magnetic, acoustic, optical, electrostatic, or pneumatic. In the case of pneumatic levitators, the object is lifted by the action of an airflow. Usually provides the flow, which passes through a grid that makes it laminar. Currently, pneumatic levitation systems are widely used in the transport of materials like food or medicines, which have strict hygiene parameters or require low friction of materials that are being moved [1].

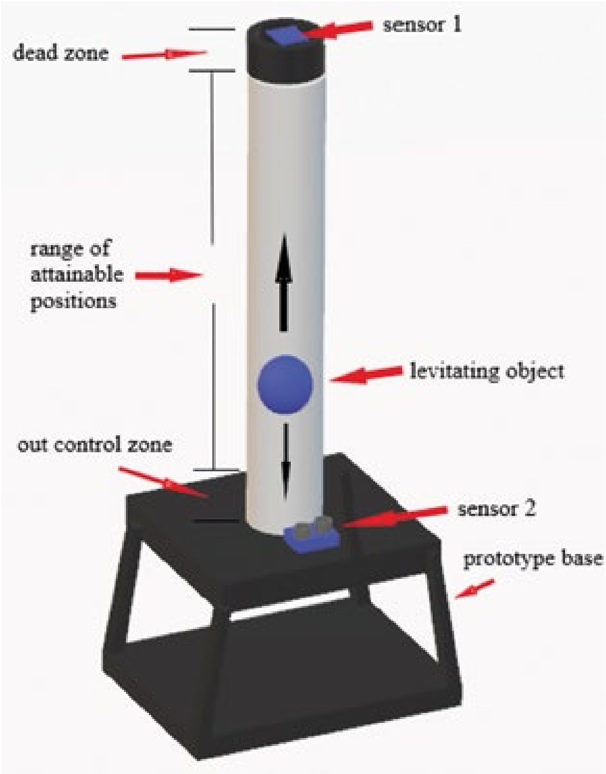
When the pneumatic levitators are considered as an academic resource for control learning, the control objective is to keep the position of a ball inside of a pipe; where a sensor measures the ball position. Figure 1 shows an example of a structure for a pneumatic levitator. For estimating the mathematical model, researchers generally neglect the porosities and imperfections of the object, and effects of the friction forces in the horizontal movement and rotational movements resulting from the Magnus effect, [2]. Likewise, they approximate some physical constants such as the drag coefficient and the density of the object and pay attention to aspects such as the dead zones of the sensor and fan, which generates a range of positions that cannot be controlled, see *Figure 1*.

Different structures and controllers have been implemented for pneumatic levitator. For example, in [2], the authors show the identification and position control of a pneumatic levitation system using a compressor driven by a variable velocity drive; they compare the results obtained of implementing an H∞ control, a PID control and an incremental fuzzy control. Reference [3] presents the mathematical model and a controller for a pneumatic levitation system as well as the construction of a prototype for the experimental validation of a linear controller which is implemented by using the state feedback. In [4], the performance of a conventional PID controller and an expert FUZZY controller are evaluated for reference tracking and in rejection of disturbances. In [5], an experimental study of different nonlinear PI controllers is presented, for that, authors use an academic platform based on an air levitation system.

The pneumatic levitator has also been used to perform different stability analysis tests for rejecting disturbances. For example, reference [6] shows the design and construction of a virtual laboratory where the behavior of a remote pneumatic levitation system is observed in real-time. Likewise, the authors of [7] describe a pneumatic levitation system to help students visualize and understand theoretical concepts in control engineering. Likewise, in [1], authors describe a mathematical model and a 3D simulation of a pneumatic levitator, in the experiment the forces involved in the system are increased for calculating the parameters of a real levitator. Finally, the most significant advance is the patent that exists on a pneumatic levitation train known as Hyperloop, which aims to transport people at speeds never reached. The patent is not yet available; however, in [8], a general description of the project is discussed.

Figure 1

Vertical Pneumatic Levitator



Source: Own elaboration

This article presents the design of a prototype of pneumatic levitator that is used as a plant for control education. This prototype is characterized for having a size for facilitate its use in the classrooms, it is a practical tool, playful resource and inexpensive lab set-up. Moreover, the prototype has a human-machine interface, which allows to the user operate the prototype in a remote way.

The rest of the paper is organized as follows, Section 2 show the modeling of the system and its linearization at an operating point, the design of a digital position PID controller by means of pole assignment and the simulation results; in Section 3 presents the performance of the designed controller and the use of App for monitoring the variables. Finally, Section 4 shows conclusions.

Prototype description

After reviewing the state of art of the pneumatic levitator, students obtain the mathematical model by using the studied theory. Based on the model, they build the prototype, firstly a designing a model in a graphic editor, this information is used to cut the pieces that will comprise it; later, selecting the appropriate materials and devices like sensor, actuator, digital platforms (e.g., Arduino) and power supplies; and Finally, they implement and adjust the prototype components to have a final version. Once the prototype is finished, students test its performance and behavior before to design the controllers.

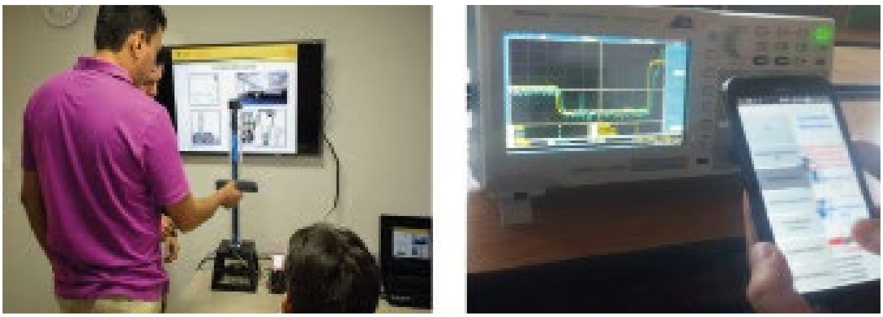
Mathematical model of the plant

Taking into account the literature review, the students obtain a nonlinear mathematical model of the plant in state space, Equation (1), taking into account the physical considerations shown in *Figure 2*. After that, students define an operating point, for obtaining a linear model of the system in state space Equation (4) and (5).

In *Figure 2(a)*, the reader can observe the prototype, in *(b)* the set-point signal (in yellow) vs. the output system (in green), these signals are directly measured with the oscilloscope in the plant.

Figure 2

(a) Pneumatic levitation plant; (b) plant response seen from the oscilloscope



a) b)

Source: Prepared by the authors

Non-linear mode.

The mathematical model of a pneumatic levitation system involves mechanical, electrical and aerodynamic principles, such as: i) principle of continuity because the air flow is constant through the cylinder; ii) Bernoulli principle because the force applied by the flow of Air to the object depends solely on the kinetic energy, Euler-Lagrange equations because with these any system can be represented with respect to its energy variation; and iii) Raleigh dissipation function for the modeling of the viscous friction experienced by the object, number of Reynolds (*Re*) quantity to be taken into account for the calculation of the drag coefficient *CD*.

The non-linear in state space representation of the system is in Equation (1).

$$[\dot{x}1 \; \dot{x}2] = \left[x2 \;\; \frac{Af^2 * Vf^2 * \rho a - 2 * CD * \rho a * Ab^2 * x2 - 2 * Ab * mb * g}{2 * Ab * mb}\right] \quad (1)$$

Where, *x1, x2* are the position and speed of Object, respectively; A_f is transversal area of the tube; V_f is air velocity in the cross section of the fan; ρa is air density; *CD* is drag coefficient; *Ab* is transversal area of the levitating object; *mb* is Mass of the levitating object and *g* the gravity constant.

Linear model.

To use the linear control techniques, linear model is obtained for a operating point. The Equation (2) describes the process to obtain the equilibrium points in Equation (3) the expression for Jacobian.

$$[0\ 0\ ] = \left[x2\ \frac{Af^2 * Vf^2 * \rho a - 2 * CD * \rho a * Ab^2 * x2 - 2 * Ab * mb * g}{2 * Ab * mb}\right] \tag{2}$$

$$[\dot{x1}\ \dot{x2}\ ] = \left[\frac{df1}{dx1}\ \frac{df1}{dx2}\ \frac{df2}{dx1}\ \frac{dx2}{dx2}\right] * [x1\ x2\ ] + \left[\frac{df1}{du}\ \frac{dx2}{du}\right] * u(t) \tag{3}$$

Where:

$$f1 = x2;$$

$$f2 = \frac{Af^2 * Vf^2 * \rho a - 2 * CD * \rho a * Ab^2 * x2 - 2 * Ab * mb * g}{2 * Ab * mb};$$

$$u(t) = Vf$$

Finally, the linear model in state space representation of the system is described by Equation (4).

$$[\dot{x1}\ \dot{x2}\ ] = \left[0\ 1\ 0\ -\frac{CD * \rho a * Ab}{mb}\right] * [x1\ x2\ ] + \left[0\ \sqrt{\frac{2 * Af^2 * \rho a * g}{Ab * mb}}\right] * u(t) \tag{4}$$

$$[y] = [1\ 0\ ] * [x1\ x2\ ] \tag{5}$$

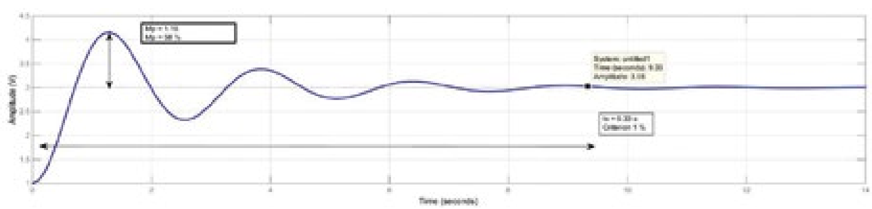
Taking into account the actual parameters of the plant, the system transfer function is:

$$Gp(s) = \frac{6.221}{S^2 + 0{,}8488S} \quad (6)$$

The system has a pole at zero, which provokes an integrator effect; for this reason, the response in closed-loop (see *Figure 3*) was analyzed to determine which parameters could be improved. The response of the system scaled in volts is shown in Figure 3, where 0 cm equals to 0V and 53 cm equals 5V. A step-test was used to obtain an experimental model, changing the input signal from 10.6 cm (1V) to 31.8 cm (3V), an over peak of was observed in the output signal and a stabilization time of *Mp%=58 % and a* t_s *= 9.33 [s].*

Figure 3

System response to a reference change in closed loop without controller, using Matlab2014



Source: Own elaboration

PID controller design

As desired parameters for system, student define:

$$Mp\% = 25\ \%; \quad t_s = 2\ s;$$

$$\xi = \sqrt{\frac{(ln\ (Mp))^2}{\pi^2 + (ln\ (Mp))^2}} = 0{,}4; \ \ \omega_n = \frac{4{,}6}{\xi * ts_{(1\ \%)}} = 5.75\ rad/s$$

Using Diophantine Equation that compares the closed-loop characteristic polynomial to desired polynomial the constants for the PID controller are:

$$Kp\ 18.8 = ;\ Ki\ =\ 41.07;\ Kd\ = 4.3$$

To choose the sampling time, the Nyquist-Shannon theorem is used, choosing for this case a sampling time twenty times faster than the of system. Having the sampling time and the analog constants of the PID, the constants for the digital controller are obtained and these are:

$$T_m = \frac{\tau_{eq}}{20} \cong 21.74\ ms;\ Ki_d\ =\ 0.4464\ ;\ Kp_d\ =\ 9.2884;\ Kd_d\ =\ 98.896$$

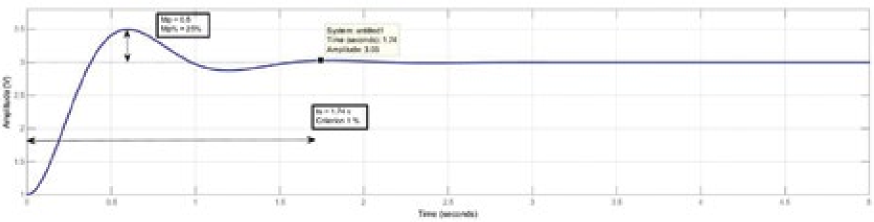
Finally, the control law that is implemented in the microcontroller is:

$$u[k] = [Kp_d e(k)]_P + \left[ki_d\big(e(k) + e(k-1)\big)\right]_I + \left[kd_d\big(e(k) - e(k-1)\big)\right]_D$$

Figure 4, shows the controlled system response (blue) after making a set-point change from 10.6 cm (1V) to 31.8 cm (3V). Here it is shown how the system response has improved considerably, having a behavior as desired, with Mp% = 25 % and also the settling time is less than expected.

Figure 4

System response to a reference change in closed loop with controller, using Matlab 2014



Source: Own elaboration

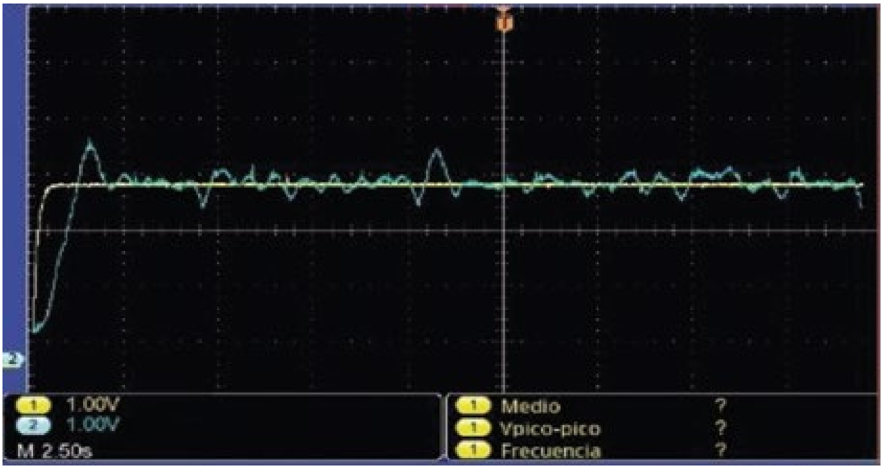
Results

Figure 5 shows the comparison of the controlled system response (blue line) and the set-point (yellow line), when the set-point is changes from 6.36 cm (0.6V) to 33.92 cm (3.2V), the reader can observe that some parameters of actual response are little different to those obtained in the simulation.

$$K = 1; \quad M_p\% = 30.8\,\%; \quad tp = 1{,}5\text{ s}; \quad ts = 2{,}5\text{s}; \quad \xi = 0{,}341; \quad \omega_n = 2{,}23 rad/s$$

Figure 5

System response to a reference change in closed loop with controller, using oscilloscope



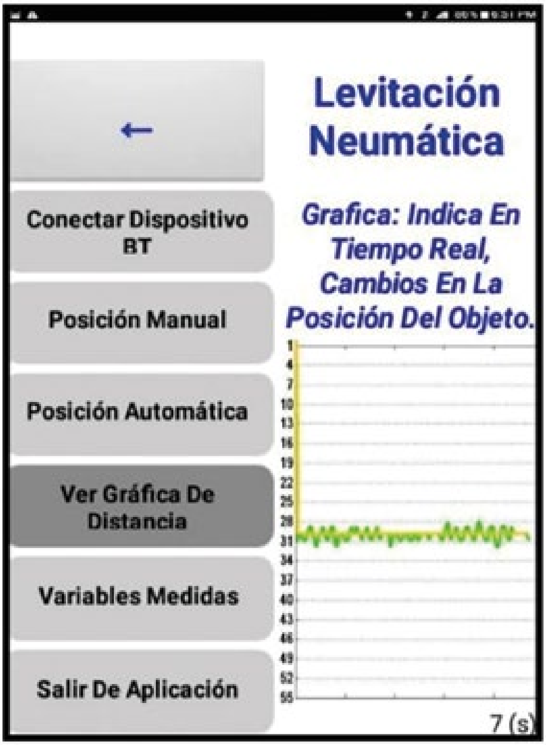
Source: Own elaboration

Figure 6, shows the response of the closed loop system with controller (green graph), vs the reference change (yellow graph), since the android application. The application has a graphical user-friendly interface, it also has a menu that allows: connection to the Bluetooth device, choose the position of the levitator object, see the graph of the reference and control signals, and see the status variables, all in real time.

The oscillations in steady state are due to the resistive forces that are generated when the air flow hits the sphere, to improve this, an advanced control that compensates for the non-linearities of the system is required. The application has a graphical user-friendly interface developed in App Inventor, which has a menu that allows connecting Bluetooth devices. The user can change the set-point for the system by using the option available in the menu. *Figure 6* shows the final view of the user interface, which also has a plotter to observe the set-point (yellow line) and system output signal (green line) in real-time.

Figure 6

App in Android for monitoring the signals and adjusting the set-point



Source: Own elaboration

Conclusions

Considering that the PID controller was designed using the linear model of the system, whose non-linear model is an approximation to its actual behavior. Researchers observed that the performance of the controller was the expected, which was observed for an abrupt change of set point was applied during the testing stage, where a maximum overshoot of 32 % and a stabilization time of 2.5 was calculated for these operating conditions indicating an improving of the system response.

The application on Android allows observes what is happening with the plant in real time; in addition, it is possible that the user selects the position in which he/she wants to place the levitation object. This application has a very easy to use and results a didactic tool to observe the variable behavior of the plant.

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Virtual navigation of a micro robot guided by haptic interface

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Abstract

The theoretical and experimental advances of micro robotics have grown at a high speed in recent years, perceived as a technology that will revolutionize in the near future medical procedures as diverse as the performance of tests that were generally invasive, the administration of medicines and the monitoring of some vital organs, etc. In this article we will present a field of application of micro robotics, called virtual navigation of a micro robot through a software platform guided by a haptic interface. This interface provides the surgeon with convincing haptic sensations about the interaction between the micro robot and the pancreatic duct, and allows him to intuitively control the position of the micro robot in a 3D space. Virtual designed navigation simulates both the trajectory and its collisions with the pancreatic duct, providing realism in the exploration of this organ.

Keywords: Virtual simulation, haptic interface, micro robots, virtual navigation, 3D modeling.

Precedents, motivation and objective

Recent technological advances in surgery allow the development of a series of new techniques that, above all, have accelerated the recovery of the patient, have reduced the mortality rate and have improved the diagnostic accuracy and the therapeutic result [1], [4], [6]. A new technology is glimpsed in the field of medical robotics for the next few years: micro robots. Surgical procedures based on micro robots are currently a challenge for both scientific-clinical community and engineers [2]. Surgical micro robots are seen as means that, in the near future, will allow the surgeon to reach points in the human body that would otherwise be very difficult to access. For this, it is important initially to recreate the access to these points in a virtual way, to know the complexities involved in navigation and the locomotion of these mechanisms [3], [5]. To obtain the medical images that will guide them, different techniques are used, like the ultrasound, which has shown several advantages such as cost-effectiveness, non-invasiveness and volumetric images capturing in real time [3], [12]. In comparison with the purely mechanical instruments that must be manipulated manually, medical micro-robots have enormous advantages in terms of maneuverability due to the different tasks they can perform [5], contrasting the restricted scope when manipulation is performed by human hands.

Omni Phantom is a motorized mid-range haptic device that provides force feedback, allowing to feel 3D objects and produce real tactile sensations while those objects are manipulate in the virtual environment, improving medical or scientific simulations [7]. Because the haptic interface provides a more real perception of the virtual environment, it is possible to evaluate the performance and scope of the human-robot interaction, these evaluations have allowed to use this haptic interface for medical purposes [1], [2], [4], [8]. The integration of the Unity 3D graphics engine and the Blender three-dimensional modeling software with the haptic interfaces lead the development of functional virtual environments [7], [8] of the human digestive system, where trajectories, movement, direction are programmed and the basic actions of movement of a micro robot [8], specifically in the area of the pancreas duct. In the interaction, the action of the haptic interface reflected in the collisions of the micro robot against the walls of the pancreatic duct and the force feedback that the user experiences is evidenced.

This article presents the implementation of a tool that allows to move a virtual micro robot inside the pancreas, using an Omni Phantom haptic interface, in order to test the potentialities and functionalities that this type of devices would have for the treatment of possible diseases in a particular organ of the human body.

Materials and methods

The design and implementation of the virtual navigation of the micro robot guided by the haptic interface Omni Phantom, was carried out by means of different software tools, where the digestive system of the human being was represented graphically by means of 3D models. The pancreas was specifically chosen with its multiple internal ramifications, where the micro robot will perform its navigation at a constant speed. On the other hand, the haptic interface gives the sense of touch when micro robot collides with the walls of the pancreas duct, generating a force feedback in the user's hand. The following sections will present the different software packages used.

Unity 3D, Blender and ZBrush software

Unity 3D is a 2D and 3D development tool, used in virtual reality systems [9]. In this software, each 3D modeled organ in the Blender and ZBrush tools was included and will be explained below. In addition, the entire operating logic of the micro robot and the pancreatic duct was defined by scripts, allowing physical behaviors according to parameters found in the human body. On the other hand, Blender is a software for 3D modeling and also incorporates the possibility of giving textures and materials to them [10]. This software was used for design and development of 3D models of the pancreatic duct, stomach, pancreas, and digestive tract including the large and small intestines. It should be noted that textures and visual details of lighting were applied to each organ in order to improve its visual appearance. Finally, Zbrush is a program of 3D modeling, sculpture and digital painting [11]. This software was used for 3D modeling of the liver, because it is a structurally complex organ of modeling, mainly in the areas of the left and right lobes and in the area of the falciform ligament.

Omni Phantom haptic interface

The Omni Phantom haptic device allows for kinematic interaction with complex virtual environments, providing force feedback to the user's hand. The Omni Phantom is a motorized device that allows you to feel virtual objects and produce real tactile sensations as the user manipulates the 3D objects on the screen, in this case, in the graphic environment of Unity 3D.

Integration of the haptic interface and Unity 3D.

The integration of the Unity 3D software and the hardware that corresponds to the Phantom Omni haptic interface was done through an Ethernet card that was integrated into a computer with Intel (R) Core (TM) i5-2310 processor, CPU @ 2.90GHz and 4GB RAM. The connection of the PC to the haptic device was physically made using a connection cable compatible with the ports of the hardware elements, the protocol used for this connection was TCP/IP which provides reliable transmission of data over networks.

Flowchart of the scripts that define the behavior of the application.

The implementation of haptic interaction in Unity allows the haptic rendering of geometries taking into account the limitations of haptic rendering and the hardware capacity and processing of the devices. It is required to specify the mesh of the tangible objects, as well as the components of the transformation matrices that will be fixed in the haptic frame using some of the functions that are detailed in later lines. To get a correct functioning of the system, the following steps must be followed:

- Turn on and link the haptic device.

- Set the haptic workspace with its dimensions and set of tangible faces in the “Shape Manipulation” function.

- Work area update (orientation workspace set based on a touch camera known as Haptic Camera) in the “Shape Manipulation” function.

- Setting the interaction mode using the “Shape Manipulation” function.

- Set the haptic model and its geometry (mesh and transformation matrix) by means of the “Haptic Properties” function.

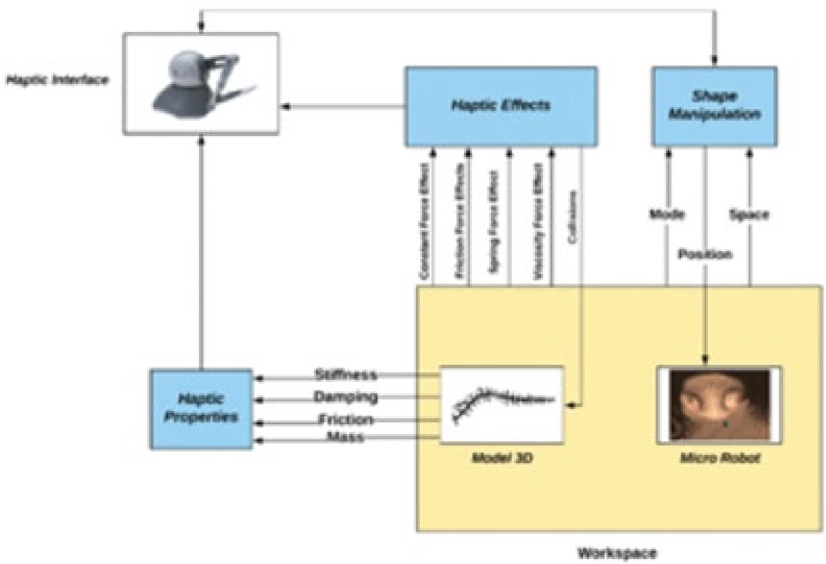
- Define the environmental and mechanical effects of the workspace using the “Haptic Effects” function.

- Execution of the interface designed in Unity for haptic events.

Shape Manipulation function allows to establish the three-dimensional coordinates of the workspace, integrate an orientation camera for the execution of haptic events and, of course, the haptic interaction mode of the workspace. On the other hand, **Haptic Properties** function establishes the haptic properties that a tangible object can have. Finally, with **Haptic Effects** function, is possible to define several types of force action that the workspace executes on the haptic model, in addition it allows to handle collisions of objects that have initiation of haptic events and comply with the aforementioned characteristics. *Figure 1* shows the various system connections between the scripts defined above.

Figure 1

Relationship of inputs and outputs for scripts



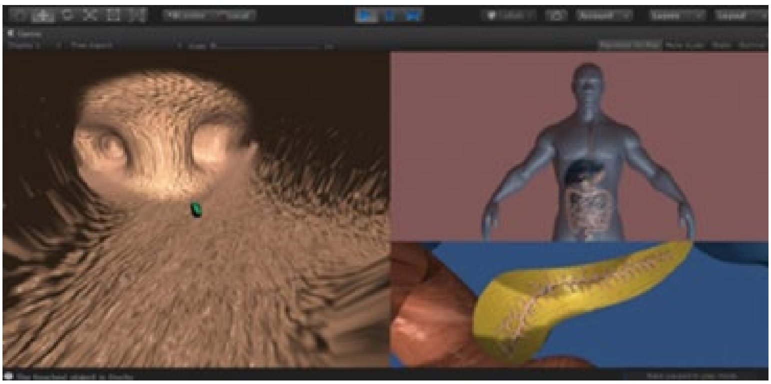
Source: Own elaboration

Results

The 3D models made in Blender and ZBrush software allowed to complement and show virtually the virtual navigation dynamics of the micro robot, specifically through the pancreas duct, these models described above were integrated into the Unity 3D graphic engine, where a scene was designed divided into two parts, as evidenced in *Figure 2*. In the right and top part is shown the patient and the different abdominal organs. On the right and lower part, you can be seen the pancreas divided in two and the pancreatic duct with its ramifications, in this section was included an arrow that constantly indicates the position of the micro robot along the pancreatic duct. The section on the left shows the execution of the simulation, i.e., the path of the micro robot in the pancreatic duct and the collisions it presents when touching the walls of the duct with the haptic interface.

Figure 2

Scene in Unity 3D for the navigation of the micro robot



Source: Own elaboration

The device can be entered into any of the designed abdominal organs, although in this case only the interior of the pancreatic duct has the characteristics of collision and therefore haptic feedback. The micro robot was designed and implemented with special attributes that define its direction in different axes, its path, speed and the collisions it generates when it collides with the walls of the pancreatic duct. Additionally, a system of cameras was implemented that allowed to improve the visualization of the 3D graphic environment and to have a georeferencing of the device inside the workspace. On the other hand, an explorer light was added in the frontal part of the micro robot to facilitate the vision of the person who is interacting with the graphic environment and the haptic interface. It should be noted that in the Unity 3D software a warning message is displayed in the lower right-hand corner, indicating the time of the collision with the pancreatic duct. Finally, *Figure 3* presents the user interacting with the application through the haptic interface.

Figure 3

Interaction and testing of the micro-robot navigation with the haptic interface within the Unity 3D environment

Source: Prepared by the authors

Discussion and conclusions

The present article presented the implementation of a tool that allows the navigation of a virtual micro robot inside the pancreatic duct, making use of a haptic interface. The tool was built with the Unity 3D software, while the abdominal organs were modeled in Blender and ZBrush, and subsequently exported to the Unity environment.

The connection between the haptic interface used, Omni Phantom with six degrees of freedom, and the Unity environment was shown in detail. The tests showed the correct navigation of the micro robot to the interior of the pancreatic duct and the feedback of force that the user feels when the device hits any of the walls of the duct.

Future works will include the locomotion of the micro robot which will be done by means of magnetic coils. It is also expected to schedule specific tasks for the device, to be performed on any of the abdominal organs.

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Simulation and manipulation of three educational robots in unity 3D environment

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Abstract

This Article shows the development of a graphic environment where the educational robots AL5B, S5-AXIS and DYI 6-AXIS are simulated and manipulated in a virtual and real environment. The elaboration of this interface takes place in 3D Unity's virtual environment, previously they were imported of the robot's parts from a CAD software. The program is enabled to move the robots individually and collectively, recording and reproducing their movement sequences in order to perform simple tasks. The results show the potential of teaching serial robotics in initial engineering subjects.

Keywords: Unity, robotics, Lynxmotion, simulation.

Background, motivation and objective

Currently, one branch of research that has achieved great advances has been robotics, as it has taken great boom due to the interaction between various areas of knowledge that converge, from areas such as home automation or "Domotic" to the aerospace sector. One area of knowledge in which robotics has had a great impact is medicine, since it has improved the rehabilitation of patients [5] or improved the results of surgical interventions [3], [4]. In addition to their classic contributions to the industry, in the near future more and more robots will be seen working and interacting with human beings, so it is becoming increasingly important that more and more people can interact with these types of devices [16], [17]. It should be noted that each device has different software that allows its execution and manipulation [12]. However, in most cases these programs are not compatible, therefore, it is very important to develop platforms that can simulate and manipulate different robotic arms, so that more people can interact and learn from these devices. Particularly in higher education, in engineering careers, it is important that students become familiar with this type of technology from the first semesters, in order to learn about robotics, programming, mechatronics, and so on. Having simple tools in this sense will make it easier to develop larger projects in more advanced terms.

In robotics, the simulation has had a great impact, because it allows establishing 3D virtual models [16], [9], [10], [2], it is able to reproduce and predict the operation of robotic devices, it identifies and plans trajectories efficiently [1], [3], [16], it allows knowing the kinematics and kinetics of these devices [16], being able to observe how they behave with respect to the space they occupy and the possible restrictions they may present. All this offers an innovative advantage which is universal, versatile, intelligent and portable [10], being useful for studies and research, also provides an approach before working with real devices through visualization, leading users without experience in programming robots to control and animate them [17], [5], significantly improving the interaction between human and machine. It is important to highlight that all this leads to a great impact in education, allowing to decrease the learning curve using virtual environments [3], achieving that people acquire knowledge [4][8], improve the time in the accomplishment of tasks [16] while they explore and investigate new forms of control and operation of the devices [7], being an immersion experience that allows working with equipment used in the professional field [4], [9].

It should be noted that among the different platforms are also ROS, Move It or Gazebo, however, due to the high performance that these tools offer, its learning curve is quite steep for users without knowledge of them. Therefore, we want to show in this document how using the Unity 3D graphics engine we can implement a simple interface with its respective connection to the controller cards of three different types of robots. Unity allows to make a user interface which can be used by people who do not have knowledge in programming. This article aims to be an academic contribution on the development of a graphical interface in the Unity 3D software, for the simulation and manipulation of three small commercial robotic arms: AL5B, S5 AXYS and DIY 6AXIS. Section 2 shows the robotic arms, the controller card on which the work was done and the hardware and software implementation of the three robotic arms, section 4 shows the results and finally the conclusions are presented in section 5.

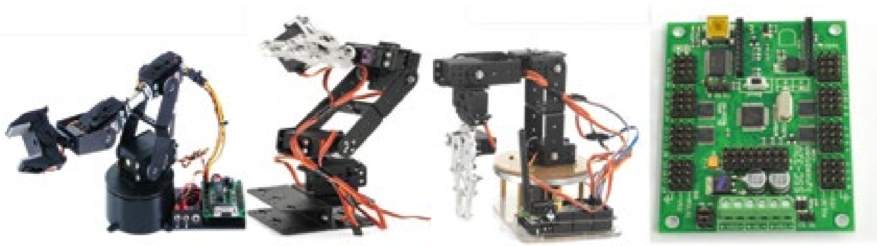
Materials / methods

Robotic arms and controller board

The robotics laboratory of the University of Cauca besides has three small size commercial robotic arms, the SainSmart 5-Axis robot, the AL5B robot, and the SainSmart DIY 6-Axis robot. These robots operate with servo motors, which have a range of motion of 180 degrees, the torsion force in one servo is up to 12 kg and its load capacity of the lower joint is up to 500 grams (*Figure 1*). The first two are robots with four degrees of freedom, plus the clamp, meanwhile the last one has five degrees of freedom, with a clamp on its terminal organ.

Figure 1

SainSmart AL5B robot, S5-Axis robot, SainSmart DIY 6 robot and controller board SSC- 32U Lynxmotion



Source: Prepared by the authors based on figures from www.sainsmart.com/ and www.lynxmotion.com/

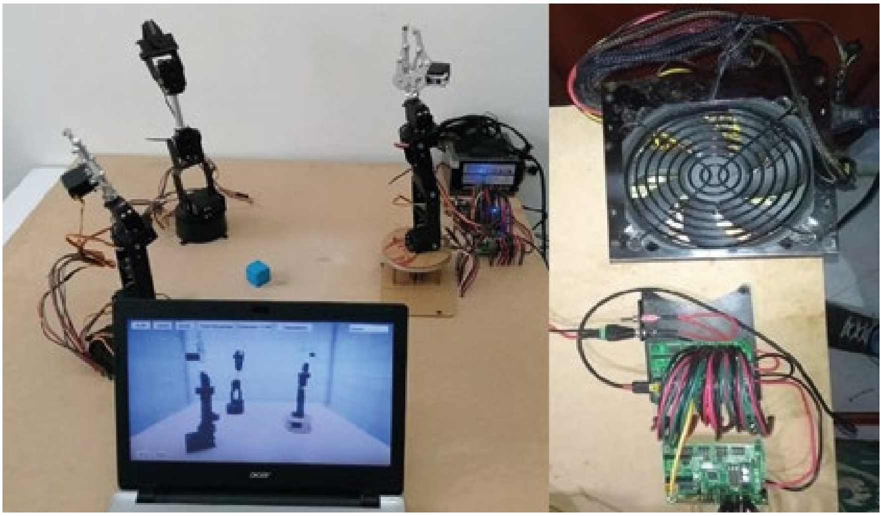
From all control cards available in market, finally it was decided to work with SSC-32u Lynxmotion controller servo, because it's able to handle up to 32 output, which is necessary to control the three robots, also has the requirement current for handling them and allows the communication without needing another card, improving response times.

Hardware implementation with three robotic arms

In order to implement a hardware that provides an easy interaction with the users, has been considered the integration of the three robots at the hardware level, for which the robotic arms were assembled on a 1m x 1m wooden board, where were positioned at points that allow interaction between themselves (*Figure 2*). The robots are located 30 cm away from each other, enough distance to manipulate objects and carry out different trajectories. After the assembly of the robotic arms the wiring was made, which allows the robots feeding and control, it was used a caliber 20 cable, which is adapted to the electrical needs of the robotic arms in terms of current and thermal resistance. A wiring that connects each of the servos with the control cards below the wooden board (black wires to ground, red to the source and green to the PWM signal) was proposed.

Figure 2

Hardware implementation of the three robotic arms and control cards



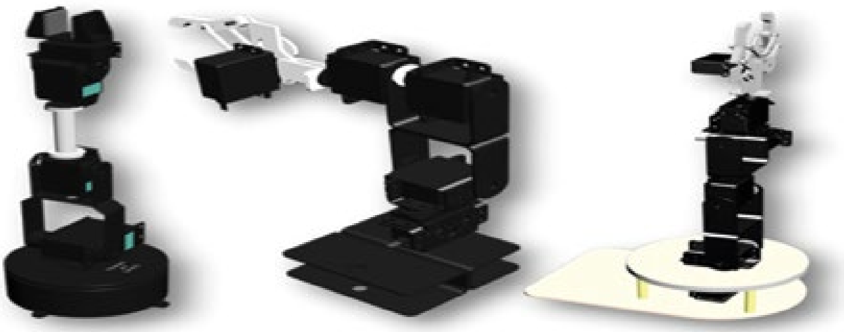
Source: Own preparation

3D robots modeling

To execute the robot's assembly in 3D Unity it's necessary import the parts of each robot from a CAD tool. The design of the pieces is developed in Autodesk Inventor and Autodesk 3ds MAX tools. The first one was used since it allows a ratio in the scale of 1: 1, meanwhile the second one allows to render the designed objects and export them to Unity, with the purpose that the simulated dynamic resembles the real dynamics. *Figure 3* shows the robots modeled in 3D.

Figure 3

Robot SainSmart 5-Axis, robot AL5B y robot SainSmart DIY 6 3D modeling



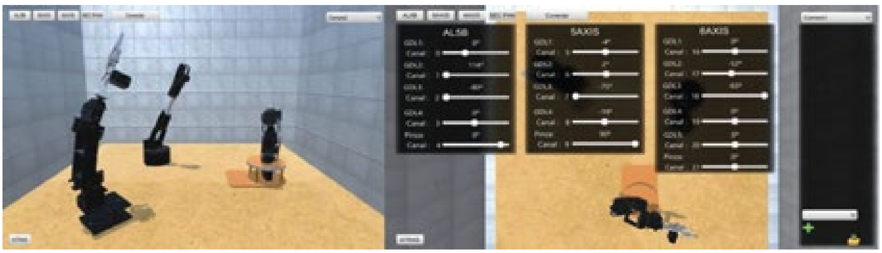
Source: Own preparation

Software implementation - User interface

To develop the graphic interface, the first thing to do is import the robots modeled in 3D. After the user interface was created where robots are modeled to scale, this interface has the option to enable different views and perspectives from the robots through two cameras. It has the buttons with the name of each robot, its respective panel is displayed where the channel is connected. It's degrees of liberty and a slider which the movement of each servo. It also has the connect button, which is responsible for bringing the robots to the initial position and connect them to the COM port defined for that purpose. Finally, we have a window where a sequence is added and where the information of the positions of the robots is observed, it is important to mention that the sequences can be saved to be used in another occasion and repeat a defined movement. This interface can be seen in *Figure 4*.

Figure 4

Interface of the tool in 3D Unit



Source: Own preparation

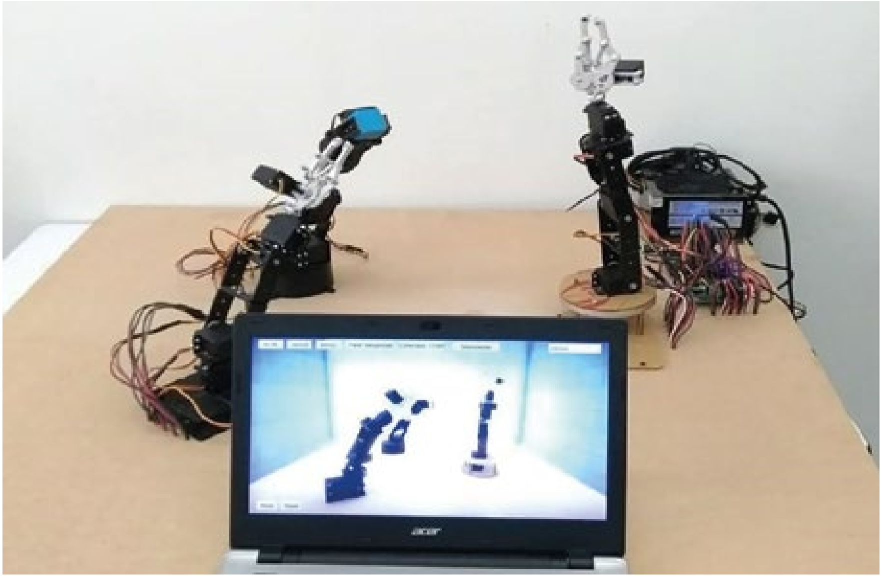
Results

To demonstrate the implementation of the software and hardware, and the operation of the user interface developed in Unity 3D, the team proposed to perform a test where the robots interacted with each other. To this end, a wood cube was used by the robots. The test consisted in three basic steps. Initially, the first robot had to take the cube from a table with its clamp. Then, the trajectory had to be planned so the cube was passed to the next robot and then to the next one. Finally, this last robot was in charge to take the cube back to the start. To accomplish this exercise, the first step was to configure the sliders movement by movement while saving the sequence. After that, the exercise was repeated with the already saved sequence. *Figure 5* shows a picture of the process.

The developed program was successfully executed in computers with different specifications and operating systems. The program has an offline installation which offers the possibility of installing the necessary programs for its correct execution. It is important to highlight that, due to the standardize developed code, the program is scalable and it allows to easily add more robotics arms.

Figure 5

Manipulation of a cube by the three robots



Source: Own preparation

Thanks to the implementation of the user interface in Unity 3D and the hardware environment of the three robots, it was demonstrated how the simulation and the manipulation of these devices are related. Moreover, the team could observe how the robots operated in synchrony and in a satisfactory manner.

Discussion and conclusions

The current article presented the implementation of a software tool that allows the manipulation of three educational robots of different characteristics. The robots for commercial purposes were the 5-axis SainSmart robot, the AL5B robot and the 6- axis SainSmart DIY robot. Since the three had the cards and programs for their use, it is a type of specific attention card to handle the three of them (SSC-32u Lynxmotion), and it is a program where they are simulated and / or controlled regarding the three real robots. The controller program was built using the Unity 3D tool, after importing the parts of the robots using CAD software. The program allows moving each of the joints of the robots through a sliding control and the sequences of movements that can be recorded and reproduced at the desired time.

Future works will implement the equations of the inverse kinematics of the three robots in order to move them not only joint by joint, but also to give them the desired three-dimensional position and where the program can be carried out. Another pending work is to be able to manipulate through a smartphone via wifi or bluetooth connection, so that you can expand the capabilities of the tool.

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Use of virtual reality for cranial navigation in surgical exploration tasks

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Abstract

The appearance of head mounted screens (HMD) has been fundamental for the development of new applications using virtual reality (VR), since these devices achieve immersion by users in a virtual world. This article shows a tool which allows the user to interact with a virtual skull from the Oculus Rift helmet. The tool was built using the Unity 3D gaming engine and the medical images were obtained from a real patient by means of a computerized tomography. The tests carried out with five users allow to foresee the potentialities of the tool for tasks of exploration and surgical diagnosis, taking into account the incidence of the simulator disease in medical students practicing surgery.

Keywords: Virtual reality, Cranial navigation.

Background, Motivation and Objective

Medicine demands precision in each of the analyzes and procedures performed, especially in surgeries, therefore the process of training a doctor should cover in detail the surgical training. The current technological advance provides new training tools such as virtual reality (VR). As mentioned by Grigore [1], it is an immersive experience that involves multimodal and multisensory interactions with simulated scenarios through a computer and fundamentally with visual, auditory and haptic feedback.

With the appearance of the head-mounted displays (HMD), computer-generated graphics within these devices were also used, and with this, not only games and entertainment were introduced, but they were also used in computer applications. engineering, medicine and simulations in the aerospace field [2]. However, it is highlighted that one of the biggest challenges faced by users when using HMD as training devices, whether it is surgery or aviation maneuvers, and even when they are used solely as an entertainment element, is the simulator disease [3] - [6] that occurs in most users with symptoms such as dizziness, headache, blurred vision, nausea and may even affect the balance.

Training programs using VR are increasingly used and complemented with HMD, presenting the user or surgeon in training [7] a perspective image of their movements, having a better immersion and making the perception as much as possible. real possible in order to obtain optimal results in the process. Novice surgeons do not feel safe to perform complicated surgery or higher surgical risk, and this is where VR technology can be used as a method to improve residents' self-confidence and knowledge. a surgery [8], since among the benefits it provides are improving fine motor skills and eye-hand coordination in preclinical settings, as well as methods that can be implemented at low cost [9].

Among many existing HMD devices, the Oculus Rift tool has been introduced with greater acceptance in research in the field of medicine and there are already several studies carried out around it that encompass topics such as the diagnosis of pulmonary disorders [10]. immersive training [11], physical rehabilitation [12], [13], education of residents [14], among others. On the other hand, a qualitative study has been developed that evaluates the interaction and / or manipulation of the user in a VR environment and using the Oculus Rift tool with 3D elements [15], however it has not yet been explored how serious this interaction would be. in a hospital or surgical environment, nor what is the reaction of the user when faced with a scene of those characteristics.

This article shows the result of the combination of the Oculus Rift HMD tool with the Unity programming environment as a support system for medicine. In particular, it tries to qualitatively analyze the user's interaction with 3D recreations of parts of the human body such as the skull and the brain, and their reaction when immersed in a scene related to this area of medicine. In this interaction, Oculus controllers play an important role since they allow the hands to be used in a genuine way and therefore the manipulation of the elements in the VR scene is achieved in a natural way, on the other hand, the viewer plays a very important role in terms of the simulation of the simulator, which finally suggests that this type of Tools can be used satisfactorily as part of non-vase surgeon training in the detection of said condition.

Creation of the application using hardware and game engine

For the realization of this project the Oculus Rift toolkit was used and as HMD the helmet or visor was used, which has two OLED screens with a resolution of 1080x1200 each, which means that the VR is fully immersive (*Figure 1*). It also has two position sensors in order to track the position of the user's head and hands, which in this case are the game controls. For this tool to be manipulated it is necessary to have a powerful graphic card and in general that the computer where it is going to work has the characteristics of a computer for games in terms of memory and graphics card.

Figure 1

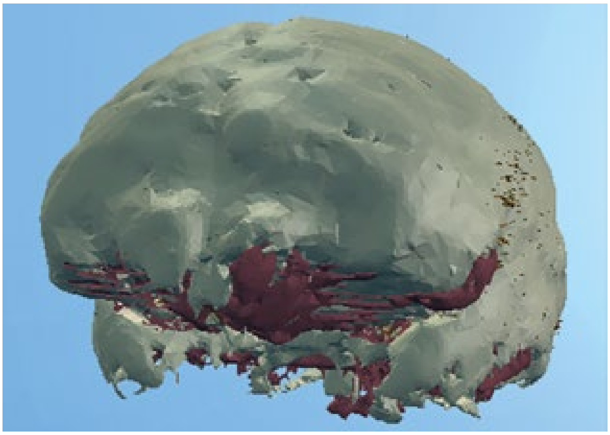
Oculus Rift Kit

Source: Prepared by the authors based in pictures from www.oculus.com.

Unity [16] is a real-time platform used for the creation of videogames, where more than half of the games that exist to date have been built. It is an easy tool to work and that provides all the facilities to create scenarios in 2D and 3D. Within Unity are integrated the necessary packages to work with Oculus Rift, which makes it a good tool for this project. The 3D models used are recreations of three-dimensional objects that are usually found in a laboratory or clinic and are also representations of some organs of the human body. For this project, the images obtained from a CT scan of a real patient were used, which were adapted to be correctly represented in the tool (*Figure 2*).

Figure 2

3D model of the human skull



Source: Own elaboration

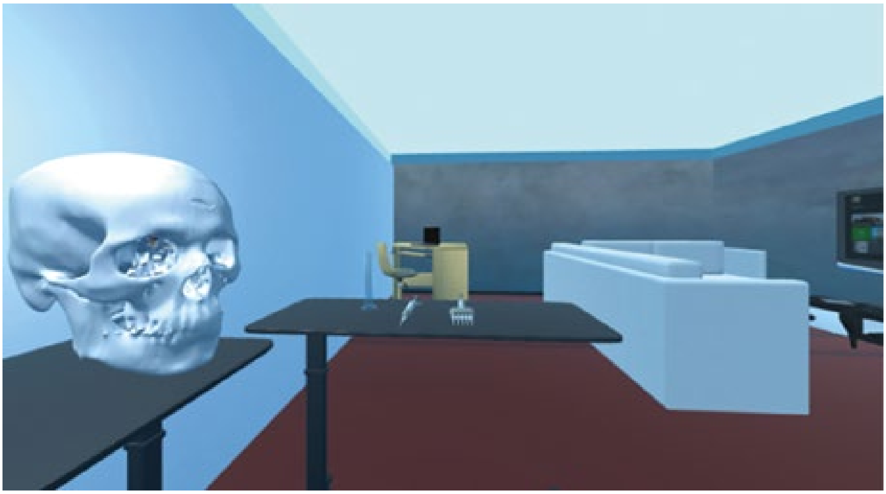
Configuration and implementation

The graphic scenario was implemented in the Unity game engine and the integration with the Oculus Rift tool was made with the help of the built-in VR support, Oculus Integration, which contains scripts, prefabs and different resources that allow manipulating the tool. To navigate through the virtual scene and manipulate the objects of the same, the OVRPlayerContro-ller package was used, which allows access to the helmet camera and Oculus controls.

When accessing the desktop application and using the HMD and the aforementioned controls, the user starts positioned just in front of where the 3D model of the skull with which he is going to interact is located. From this position, he can move freely around the room as soon as the guardian allows it, and he is able to make a 360 ° visual tour with which he can perceive the details of the creation of the virtual space and feel inside a real clinical laboratory, so feel the immersion that this powerful VR tool generates. All the objects of the scene with which the user can interact have assigned physical properties such as texture, color and gravity, they also have other scripts that allow these elements to be manipulated with the help of the controls by the user (*Figure 3*).

Figure 3

Unity scenario - Enlargement completed



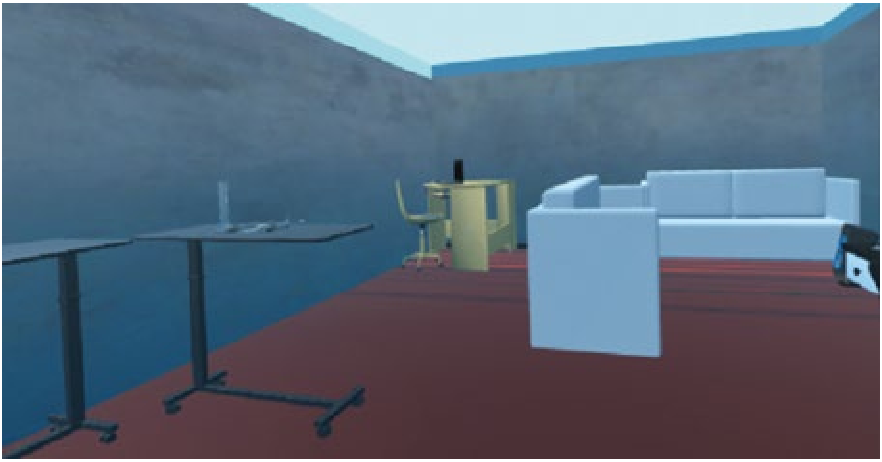
Source: Own elaboration

User interaction

During the development of the application the user mainly interacted with the skull modeled three-dimensionally, however a scenario was also adapted where he could walk all around and, in this way, have a more realistic setting of a conventional office and a room surgery (*Figure 4*).

Figure 4

Conventional office setting



Source: Own elaboration

In the final scene the action area has the necessary details to provide comfort to the user at the time of the dive, in addition other objects in the room can be manipulated. Regarding the model of the skull, its parts were differentiated for a better perception: gray matter of beige color, white matter of red wine and brick-colored corpus callosum (*Figure 5*).

Figure 5

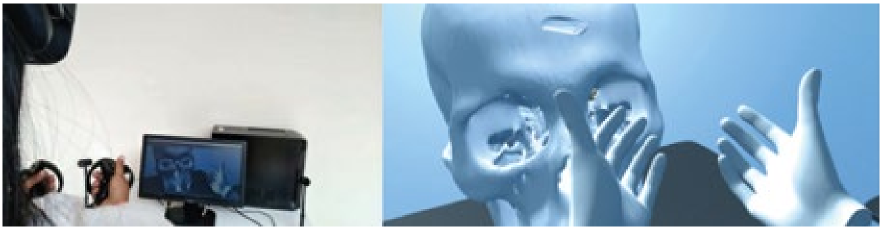
Interaction inside the skull

Source: Own elaboration

In this version, the hands of the user are simulated with the help of the controls and the Oculus position sensors, with which it is possible to visualize the grip of the 3D legs and from the grip rotate, zoom in and change its position in the scene- River. This grip is achieved in a very natural way and allows the immersion to be more real (*Figure 6*).

Figure 6

Interaction of the Oculus Rift with the application



Source: Own preparation

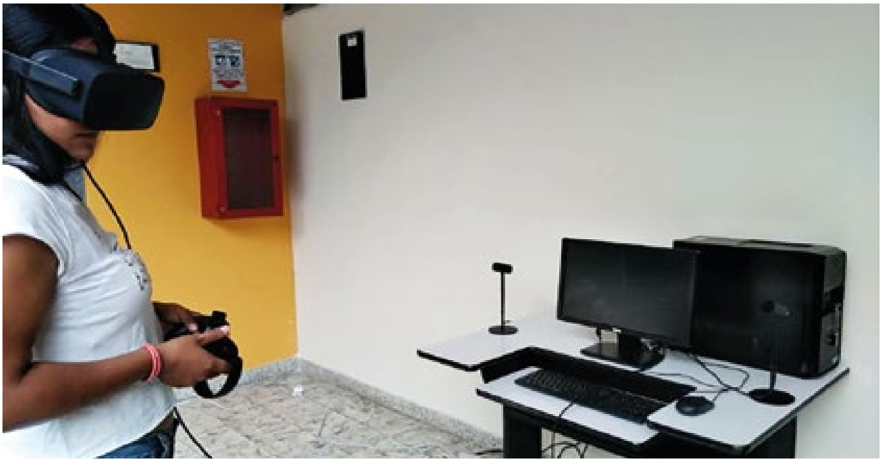
Results

The final application achieves the user interaction with the 3D model of human organs and surgical tools, which was tested by five users who in their entirety presented a good acceptance of the product and experience. They denied having experienced dizziness or cyber disease, which is one of the most frequent effects when using HMD helmets.

All the users were comfortable with the immersion in the VR scene and expressed the ease of manipulating virtual objects, which also have the right size for their interaction. They also thought about the need to set the scene with elements that remind them that they are in a hospital environment, the relevance of being able to perform different actions with the objects to be manipulated, rotated, approached, grasped and able to move. around the scene in such a way that the immersion becomes stronger. On the other hand, users stressed that the tracking of the movements of the head during the test of the application was quite good, which in turn allowed to have a good handling of the controls, which are represented as the hands of the operator. Finally, it is recommended that the workspace be large enough so that the user can go through the entire scene without any restrictions. In *Figure 7* a user is observed testing the application.

Figure 7

User testing the simulator



Source: Own preparation

Conclusions

The present article showed the construction of a tool that allows the interaction of a virtual reality helmet for medical exploration inside the skull. The tool was made with the Unity game engine and integrated with the VR Oculus Rift case. A virtual environment was created that shows the inside of a patient's skull obtained through a computed tomography.

The tool was tested with five users who expressed the ease of handling and the quality of the immersion inside the skull.

Future work will implement specific tasks within the skull and will evaluate its potential as a medical trainer, in addition, they denied presenting symptoms of cyber disease.

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Prototipo de sistema automatizado para cultivos de tomate con iluminación LED en INDOOR

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Resumen

La tecnología LED por su versatilidad y aplicabilidad, se utiliza en diversos escenarios tanto industriales, como en el hogar para facilitar la vida de las personas. En este artículo se presenta el diseño de un sistema automatizado, utilizando tecnología LED para el cultivo de tomates, considerando el incremento de cultivos de alimentos en entornos controlados. El sistema está construido utilizando un conjunto de tecnología de hardware de bajo costo y herramientas de software. Se presentan los resultados preliminares del prototipo construido, obtenido en las diferentes pruebas realizadas, donde se pudo comprobar la eficiencia de implementar luces LED en cultivos; mostrando así la evolución del desarrollo de crecimiento mediante una comparación del mismo cultivo sometido en dos ambientes distintos: uno controlado, el cual tuvo una aceleración en su crecimiento mayor que el cultivo que se sometió a un ambiente no controlado.

Palabras clave: Cambio climático, iluminación LED, cultivo INDOOR, placa Arduino, SciKit-Fuzzy, sensor.

Antecedentes

La luz LED está experimentando un importante auge en la horticultura internacional como una fuente de luz innovadora. Las perspectivas que ofrecen los LED son muy prometedoras. La iluminación con LED ya es actualmente entre un 30 % y un 46 % más efectiva. Esto se debe a que las plantas asimilan la energía irradiada por los LED, de un modo más eficaz que la de las lámparas existentes. Con respecto al ahorro de energía, los resultados son aún más impresionantes: la diferencia con las lámparas convencionales alcanza en algunos casos el 80 %. Con respecto a la vida útil, los LED también superan fácilmente a otras lámparas [1].

Iluminación artificial (LED)

En esencia basados en el argumento anterior surge la necesidad de proponer y poner bajo prueba un sistema de iluminación capaz de estimular eficiente y positivamente el proceso de la fotosíntesis en algunas plantas, para cultivos en interiores donde el control total y/o parcial y automatizado de procesos o tareas pueda revelar la importancia de la iluminación artificial LED. De esta forma, la iluminación artificial para el crecimiento de las plantas funciona de tres maneras distintas o diferentes como se mencionan a continuación [2]:

- Proporcionan toda la luz que la planta necesita para crecer.

- Complementan la luz natural, sobre todo en los meses de invierno, donde las horas de luz día son cortas.

- Aumentan el periodo de la luz día con el fin de disparar el crecimiento y la floración.

Relación entre la luz y el crecimiento de las plantas

Las plantas requieren luz a través de toda su vida útil, desde la germinación hasta la floración y la producción de frutos y/o semillas, aprovechando que la luz es una onda electromagnética que viaja a través del espacio y existe como paquetes de energía discreta, llamada fotones. Las variables que describen una medición de luz son: Footcandles, lux, watts, µmol/m2/s y mol/m2/day [3].

Así, la energía que es suministrada por cada fotón desde un sistema de iluminación artificial LED particular a las plantas es de:

- Longitud de onda – Color Azul 458 nm: 434,279x10-21 J

- Longitud de onda – Color Rojo 656 nm: 303,201x10-21 J

Lo que indica que el dispositivo LED de 458 nm (color azul), es mucho más energético que el de 656 nm (color rojo). Por este y otros motivos, las fuentes de iluminación LED para cultivos en interiores implementan menos dispositivos de este tipo en sus sistemas [4].

Existen tres parámetros de luz de crecimiento comúnmente usados: calidad, cantidad y duración; todos con diferentes efectos sobre el desarrollo de las plantas [5].

Cultivo de tomate

Existen diferentes tipos de tomates; no obstante, todos ellos tienen en común propiedades nutritivas. El tomate es un alimento fruto de la tomatera que no puede faltar en las casas, ya que su versatilidad les permite preparar distintos tipos de platillos, además de ser un alimento fuente de vitaminas (A, C, E, B1, B2 Y B5) [6], y minerales, los cuales son muy nutritivos y bajos en grasas. Estas propiedades hacen del tomate un alimento muy beneficioso para la salud.

Una vez evaluado los diferentes tipos de tomates se tiene a disposición para cultivar el ***Solanum lycopersicum,*** el cual es conocido como Tomate de la variedad Criollo en Panamá. Dada su versatilidad y fuentes de vitaminas se selecciona este tipo de cultivo, además de los mencionados a continuación:

- Tiene mayor resistencia ante algunas afecciones de las que padecen los cultivos de tomates tradicionales.

- No es necesario estar regándola con sustancias fungicidas.

- No ocupan mucho espacio en los huertos de cultivo, ya que el tamaño del tomate es similar al tamaño de una cereza, llegando a medir entre 1 y 3 centímetros de diámetro.

- Combate el envejecimiento, además de ser un buen reductor de enfermedades cardiovasculares y un excelente diurético, gracias a la presencia de antioxidantes como hierro, potasio y sodio.

Motivación

La creciente urbanización y el auge mundial de la construcción han subrayado la importancia de la eficiencia en el entorno ya construido, es decir, en las urbes. Para el 2050, se estima que el 78 % [7] de la población vivirá en zonas urbanas; en la actualidad, cerca del 60 % (que equivale a 4.099 millones de habitantes) lo hace. Para esta fecha la población urbana mundial habrá aumentado aproximadamente a 7.784 millones, lo que representa un 2.9 % de aumento de población por año, en un mundo en desarrollo [8]. Muchos expertos sostienen que a menos que se ejecuten medidas drásticas, el mundo podría enfrentar una escasez dramática tanto en comida como en la tierra cultivable. La hambruna y las catástrofes ecológicas son algunas de las posibles graves consecuencias debido a las ya conocidas inundaciones, envenenamiento de cultivos, heladas fulminantes e incendios forestales [2].

Objetivo

El principal objetivo de esta propuesta estuvo orientado a diseñar y construir un prototipo de un sistema automatizado para el cultivo de tomates en interiores con iluminación LED. Para esto se definieron diferentes tareas que involucraron la recopilación de conceptos sobre iluminación LED para cultivos en interiores, la identificación de cultivos para la prueba con iluminación LED, el desarrollo de un sistema que integra sensores, riego automatizado y una placa Arduino implementados en el sistema.

Materiales

La *Figura 1* muestra el diagrama del sistema que se implementó como prototipo para el cultivo de hortalizas (Tomates); y la *Figura 2* muestra el prototipo de la zona de cultivo implementado.

Figura 1

Diseño conceptual del sistema

Fuente: Elaboración propia

Figura 2

Prototipo implementado

Fuente: Elaboración propia

Se describe cada uno de los materiales implicados en el diseño del prototipo y descripciones de cada uno de estos.

ARDUINO MEGA 2560 R3 A: De los distintos tipos de placas Arduino que existen, se escogió el mega ya que brinda un microcontrolador ATmega2560, con un voltaje de funcionamiento 5V, la cual requiere una entrada de 7-12V. Se seleccionó esta placa ya que permite controlar múltiples funcionamientos y control de sensores para controlar y emular el ambiente natural [9].

Lámparas Full Spectrum LED Grow Light: Permiten tener un sistema de amplio espectro, con una potencia de 50W, una luminancia 70 lm/W, además de tener un rango de vida de 50,000 hrs. En cuanto a lo longitud es apropiada para cultivos en interiores ya que sus dimensiones son de 250x125 mm / 9.84x4.92'' y su material principal es de aluminio el cual es un buen conductor de calor.

Sensor de Humedad de suelo higrómetro YL69: Este sensor permite medir la humedad del suelo que tiene el cultivo de tomates. Detecta la cantidad de humedad que hay en el suelo, la cual posee una sensibilidad ajustable, con salidas analógicas que son más precisa al momento de medir datos para controlar el nivel de humedad, el mismo contiene un chip comparador LM393, el cual es muy estable.

Sensor DHT22: Es un sensor que permite mediciones de temperatura y humedad relativa (RH). El sensor posee una interfaz serial propietaria, que solo requiere de un pin para comunicarse con un microcontrolador [10].

Electroválvula solenoide FPD360A006 ½'': Esta válvula eléctrica permite controlar el paso de fluidos (sistemas hidráulicos). La apertura o cierre de la válvula se basa en impulsos electromagnéticos de un solenoide (un electroimán), que trabaja junto a un muelle diseñado para devolver a la válvula a su posición neutral cuándo el solenoide se desactiva [11].

Microaspersores: Están destinados a suministrar el riego mediante gotas muy finas. Poseen un deflector giratorio, denominado rotor o bailarina, que ayuda a ofrecer un mayor diámetro de cobertura, una menor tasa de precipitación que los difusores, un mayor tamaño de gota, y una mejor distribución del agua (sobre todo en uniformidad de distribución) [12].

Métodos

A continuación, se presentan los elementos utilizados en la implementación del prototipo de sistema automatizado para cultivos de tomate con iluminación LED en *indoor*; la metodología implementada en los periodos de luces y la lógica seleccionada.

SciKit-Fuzzy. Es una colección de algoritmos de lógica difusa destinados a usarse en SciPy Stack, escritos en Python, es una metodología basada en la idea de que la "veracidad" de algo se puede expresar a través de un continuo. Esto quiere decir que algo no es verdadero o falso, sino parcialmente verdadero o parcialmente falso. Un sistema de control difuso vincula variables difusas utilizando un conjunto de reglas. Estas reglas son simplemente asignaciones que describen cómo una o más variables difusas se relacionan con otra. Estos se expresan en términos de una declaración IF-THEN; la parte IF se llama el antecedente y la parte THEN es el consecuente [13].

Periodos de luces en el cultivo. La planta de tomate es una planta que necesita de mucho sol, por lo cual no es recomendado ni siquiera intentar tener cultivos de tomates en huertos dentro de las terrazas, ya que estas deben recibir al menos seis horas de luz diarias o simplemente el cultivo no produce. Por ello, se plantea una emulación de la luz del sol diaria que debe recibir este cultivo de hortalizas de la siguiente forma seis horas de luz y dos horas de oscuridad la cual se repetirá en tres periodos diarios de la siguiente forma.

Tabla 1

Periodos de luz y oscuridad propuestos

Periodos de luz	Periodos de oscuridad
• 10:00 pm – 4:00 am	• 4:00 am – 6:00 am
• 6:00 am – 12:00 pm	• 12:00 pm – 2:00 pm
• 2:00 pm – 8:00 pm	• 8:00 pm – 10:00 pm

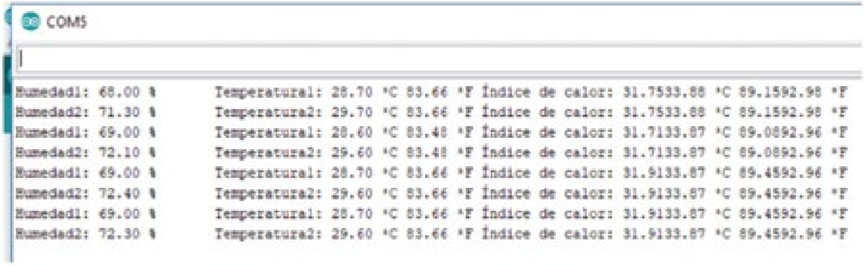
Riegos implementados. Dada la concentración de calor que se genera dentro del invernadero fabricado, se implementaron dos tipos de riegos: el riego por goteo controlado por una válvula solenoide, la cual impedía o no el paso del agua dependiendo del nivel de humedad que le arrojaba el sensor; y el riego por aspersión, que era utilizado para bajar la temperatura cuando esta ascendía a valores mayores de lo requerido para el cultivo.

Resultados

Los resultados se dan con base en una prueba de 25 días de funcionamiento ininterrumpido del prototipo. Se registró la evolución del crecimiento de las plantas de un mismo tipo de cultivo con dos condiciones ambientales diferentes: un ambiente controlado, cuyas plantas fueron afectadas por distintos periodos de luces y oscuridad como se muestra en la *Tabla 1*; y el otro ambiente en condición natural (no controlado). Los valores obtenidos de las distintas mediciones de temperatura del lugar y humedad del suelo se pueden observar en la *Figura 3*. Dichos valores se utilizaron para controlar el ambiente en el cual los cultivos pueden desarrollarse adecuadamente y su crecimiento sea mucho más rápido que estando en un ambiente natural (no controlado).

Figura 3

Valores obtenidos de las mediciones de temperatura y humedad



Fuente: Elaboración propia

En la *Figura 4* se muestra una imagen del cultivo en condiciones ambientales controladas, que puede compararse con el cultivo de la *Figura 5*, en condiciones no controladas. Los resultados son significativos ya que los cultivos en condiciones controladas crecieron 10 cm más (ver *Figura 4*) que los cultivos que se mantuvieron en un ambiente no controlado (ver *Figura 5*), lo que sugiere que el factor de emulación con luces LED es provechoso para el crecimiento de los cultivos en un ambiente controlado, además de que los mismos se mantienen en condiciones óptimas de modo que no son afectados por ningún tipo de plaga, en comparación a los cultivos no controlados.

Figura 4

Comportamiento del cultivo en ambiente controlado

Fuente: Elaboración propia

Figura 5

Comportamiento del cultivo en ambiente no controlado

Fuente: Elaboración propia

Conclusiones

Las condiciones de iluminación a las que se sometió el cultivo en prueba generaron una diferencia significativa, ya que controlando o alterando los periodos de luz y oscuridad a dicho cultivo, este se desarrolló mucho más rápido. El empleo de luces LED como emuladores de la luz solar es de gran utilidad, ya que estas tienen propiedades de color que son de provecho en el desarrollo de las plantas, de modo que las ondas de luz generadas benefician el desarrollo de los cultivos. Además, la implementación de los sistemas de riego ayuda a controlar las distintas situaciones adversas que se presentan en el cultivo.

Esta tecnología puede ser extendida a cualquier tipo de cultivo, siendo esto provechoso para las personas que no tienen donde cultivar, además de que las tecnologías implicadas en el mismo son de bajo costo.

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Open Source Six Degree of Freedom Manipulator Robot

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Abstract

This paper presents the development of a six degree of freedom 3D printed robotic arm, with an angular morphology. Our development process integrates and exploits the benefits of open-source technologies such as open CAD design for robot structure definition, free configuration electronic devices and the Robotic Operating System (ROS) a standard and powerful robotics middleware. This project shows how using open-hardware and open-software technologies is possible to develop a high-tech, low-cost, replaceable, flexible, and easy to use manipulator robot.

Keywords: open-source technologies, ROS.

Introduction

Robotics of manipulators was the driving force for the industrial implementation of different robots with a defined number of degrees of freedom to fulfill specific tasks in an efficient and precise way. In our country the implementation of manipulator robots for SMEs (Small and mid-size enterprises) are high cost and exclusive. The use of open-source platforms is getting increasingly for the possibility of having full control on the robot features. Some features of the robot such as appearance, mechanical and electronic devices, and control methods can be change for personalize the usability of the robot for specifics needs [1].

The 3D printing has been widely recognized as a valuable and efficient technology for low-cost manufacturing. Due to the ability to manufacture various 3D object designs from CAD models in relatively short time with minimum cost and efforts. Using 3Dprinted prototypes, researchers and educators can benefit from lower expenditures, easier equipment maintenance and repair, better availability of spare parts, higher relevance and flexibility of adaptation to research needs [2].

The benefits of the open-source approach

Open-source tools refer to software and hardware developments that can be acquired, modified and distributed freely. A first benefit is in regarding research, the use of this platforms in studies that employ robotics fields for leveraging low-cost technologies to make different prototypes. A second benefit is the possibility of having full control where the studies have replicability for industrial and educational implementation [3]. Another benefit is the repowering of robots with closed obsolete hardware and software.

Open-source technologies used

- ROS is a flexible work environment with a conceptual structure and defined assistance technology (framework) for software development for robotics, it has a collection of tools, libraries and conventions to simplify the creation of complex and robust robotic systems [4]. ROS is an operating system for open-source robotics that has been developed with the help of the entire acquisitive community of the framework that is compatible with the Ubuntu platforms [4].

- MoveIt! Movement planning framework. Platform for the advanced development of robotic applications (control, trajectory planning, handling, perception, collision detection and kinematic processes). Evaluation and design and integration of robotic products for industry, commerce or other domains [5].

- Rviz 3D viewer to show sensor data and ROS status information. The use of RViz allows to visualize the current configuration of a robot in a virtual model of it, it can show live representations of sensor and data values [6].

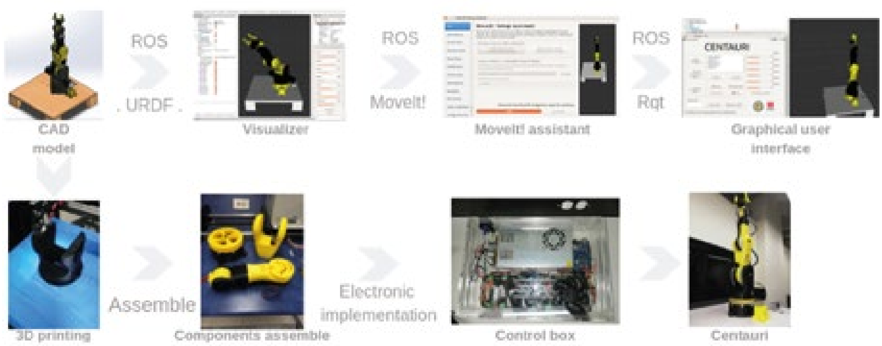
- BCN 3D Moveo an open-source robotic arm that can be modified and replicated with five degree of freedom [7].

Centauri

The implementation of Centauri robot has two action lines shown in *Figure 1*. These lines of action start with the CAD model. The first line is the software development and the second line is the hardware and construction development. The BCN3D robotic arm has five degree of freedom (5DOF), to obtain a six degree of freedom robot was necessary to implement a new articulation before the end effector. A robot with six degree of freedom allows to locate a final effector in any location of its workspace [8].

Figure 1

Robot development lines



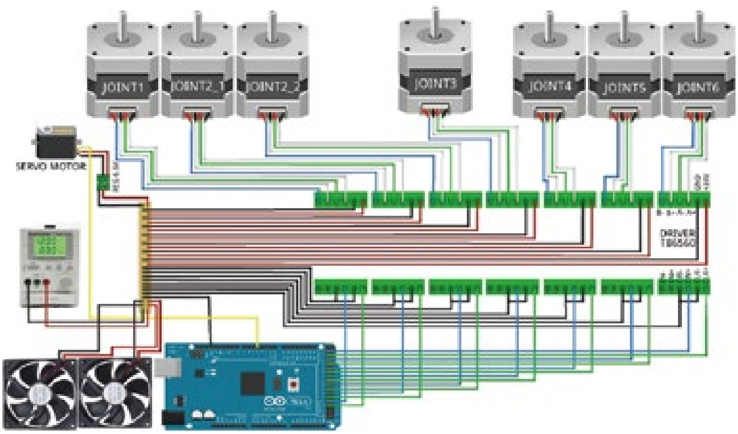
Source: Prepared by the authors

Electronics

Centauri needs seven stepper motors to work, one for each link, except the link 1 that has two motors working together. The final effector works with a servo motor. The stepper motors work with two pulses one of potential and the other one of direction. TB6560 motor driver works for motors to 12-24 V (volts) until 3A(amperes), all the stepper motors work with less that 3A (amperes) and 12 V(volts). The servomotor does not need a motor driver to work. The Arduino 2560 is a micro-controller on an electronic board, with open source platform and a development environment, it transmits the control signal to the motor drivers and the servomotor. A power-source of 12 volts feeds all the electronic devices, a refrigeration system is needs to conserve cold temperature inside the control box as show in *Figure 2*.

Figure 2

Schematic of control box



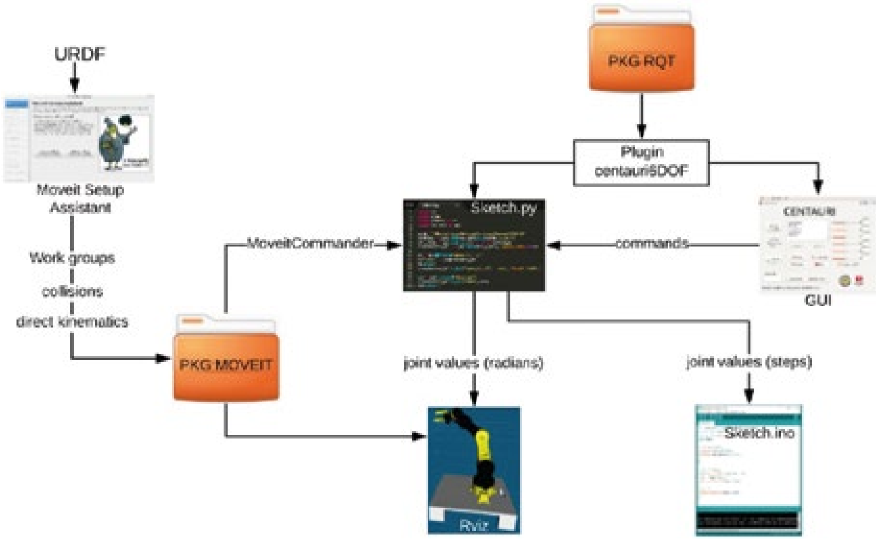
Source: Prepared by the authors

Software

For visualization in ROS, the CAD model of the robot should be exported to a URDF file. A URDF file is a description of the robot based on XML (Markup Language), that describes the robot model with values of inertia, mass, origin position, limits angles and geometry. This information is necessary for robot kinetic configuration. The verification of each joint (DOF) on the visualization can be done correctly with the ROS -joint state publisher-. This package is commonly used to interact with robot joints publishing the status of each joint as a message to the topic sensor msgs / JointState.msg [9]. Based on the URDF file, the Moveit Setup Assistant helps to create a package that contains the robot control configuration, the work groups (arm, gripper), collision matrix, the kinematic chain and more future configuration that does not include for this project like robotic perception, as shown in *Figure 3*. The Moveit package allows to send the commands by the user through the console to a programming code that interprets the commands and send it to Arduino programming code for real working and to the visualizer. Rqt is a framework based on Qt for development of graphic user interface for ROS. This framework has an interface for design and some tools for create and send actions to interact with the robot during the execution of its visualization [10].

Figure 3

Software development



Source: Prepared by the authors

System integration

For a correct functioning of Centauri robot, the software implementation must communicate with the hardware devices. ROS has a standardized communication system between subscribers or publisher nodes through the topics. Topics are the information channels. In others words the topic -joint steps- contains the joints information that this communication channel sends from the computer to the motor drivers as shown in *Figure 4*.

Figure 4

Integration of software and hardware

Source: Prepared by the authors

User interface

Without the interface, we could have controlled Centauri by console commands, but for us it was fundamental to be able to facilitate the use and control of the robot and for them we designed and built a user interface.

The graphical user interface to interact with the robot has a series of buttons and sliders that allow the movement of each joint, the execution of the end effector (gripper), the generation of poses as shown in *Figure 5*. The interface also allows to save different poses one by one to create trajectories for a specific task, the trajectories could be saved as a csv (comma-separated values) file for future use. For more information about the graphic interface, robot configuration and results of the Centauri project visit the repository available in https://github.com/andresaraque/centauri6dof

Figure 5

Graphic user interface

Source: Prepared by the authors

Conclusions

The use of open-source development platforms at the hardware and software level allows users to generate different use alternatives. The creation of new components for the morphology, the modification of mechanical and electronic devices and the implementation of new function on the software allow execute new and different functions of work with the robot.

To allow an acquiring community of the project information and the development of the same through the open-source platforms to feedback an important aspect of the design, implementation or start-up phase. This provides a more global look to reevaluate and provides greater usability of the robotic platform, all its components and configuration.

ROS as a robotic operating system and through its packages provides a wide service to make free configuration (open source) of the robot, this platform facilitates the interaction of the robot with any user that requires it and that acquires the fundamental knowledge, opening the field to robotic technologies as a universal knowledge and of free access.

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Implementation of the Screw Theory to Solve the Equations of Motions of a 4-Cable-driven Parallel Robot

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Abstract

This work shows how to implement the screw theory to solve the equations of motions of a 4-cable-driven parallel robot and the tension in each cable. Measurements were made with springs and potentiometers to compare the tension in each cable with theoretical solution. The workspace was calculated with all cables tensioned and with values below of tensile strength of the cables.

Keywords: Screw theory, cable-driven, parallel robot, workspace.

Background, motivation and objective

Forward kinematics (FK) and inverse kinematics (IK) are models that refer the analytical study of the motion of a robot [1]. FK can be used to find the end-effector position from the values of each joint of the robot. The rotating joint rotates the link to a specific angle and the prismatic joint moves the link along an axis [2].

The equations are more complex when there are more joints in the robot. In inverse kinematics the movement of joints are determined from a known position of the end-effector and the displacement of joints are unknown [3].

Screw Theory

The study of screw theory begins with Chasles in 1830 when he proposed the concept of twist motion based on mathematics methods created by Mozzi in 1763 [4]. In 1848 Poinsot developed the concepts of Chasles and after that Plücker proposed the screw expressions. Campos [4], Valdiero [5], Simas [6] and Carboni [7] have implemented screw theory to solve the equations of motions of parallel robots.

A screw consists of a line and a scalar value that represents the screw pitch. This line is called normalized screw $\hat{\$}$ when it is represented by a normalized vector [4]. According to

Hunt, the movement of an object can be simplified in a rotation and translation over an axis. The combined motion is called twist and it can be represented by the symbol $ [6]. The representation of a twist $ in Eq.1 is a combination of rotational values $[\omega_X, \omega_Y, \omega_Z]^T$ and linear velocities $[v_X, v_Y, v_Z]^T$ [3].

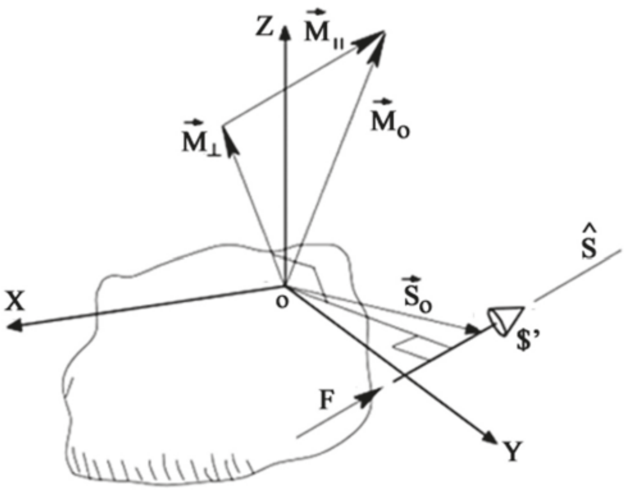
$$\$ = [\omega_X\ \omega_Y\ \omega_Z\ v_X\ v_Y\ v_Z] = [\vec{\omega}\ \vec{v}] \quad \text{(Eq.1)}$$

While the twist $ is represented by a combination of rotational values and linear velocities a wrench $' is represented in Eq.2 by a combination of forces and momentums and in the Eq.2 the wrench $' can be also written in terms of a normalized screw and a force magnitude [4]. *Figure 1* shows a wrench $' in a normalized screw and the momentum created by $'. The vector $\vec{S_0}$ starts from origin {O} to the axis of force whose unit vector is represented by $\hat{S}$. Perpendicular and parallel momentums are represented to indicate the resultant momentum $\vec{M_0}$ of the force applied in the rigid body.

$$\$' = [F_X\ F_Y\ F_Z\ M_X\ M_Y\ M_Z] = [\vec{F}\ \vec{M}] = \widehat{\$'} \cdot \mathrm{F} = [\hat{S}\ \vec{S_0}\ x\ \hat{S}] \cdot \mathrm{F} \quad \text{(Eq.2)}$$

Figure 1

Representation of a wrench $'$ in a normalized screw $\hat{\$}$ and its momentums



Source: Own elaboration

For bodies with n forces (the n cables of a cable-driven parallel robot) the sum of the forces can be applied through Eq. 3 [8].

$$\left[\vec{F}\ \vec{M}\ \right]_W = \sum_{i=1}^{n} \ \$'_i \qquad n = 1, 2, 3, \ldots \qquad \text{(Eq.3)}$$

In Eq. 3 the matrix $\left[\vec{F}\ \vec{M}\ \right]_W$ is the wrench $\$'_W$ relative to the weight of the platform and $\$'_i$ is the wrench applied on i_{th} cable of the cable-driven robot (i = 1, 2, 3, …). Applying the Eq. 2 into Eq. 3 equals Eq. 4.

$$\$'_W = [\hat{\$}'_1 \;\; \hat{\$}'_2 \;\; \hat{\$}'_3 \;\; \hat{\$}'_n] \cdot \;\; [F_1\, F_2\, F_3\, F_n\,] = J'^T \cdot \;\; [F_1\, F_2\, F_3\, F_n\,] \quad n = 1, 2, 3 \ldots$$

(Eq.4)

Where J'^T represents the Jacobian transposed matrix from the unit vectors of the wrenchs [5].

The objective of this work is to implement the equations above from screw theory to solve the equations of motions of a 4-cable-driven parallel robot and find the workspace.

Materials and methods

The cable-driven parallel robot shown in figure 2 and figure 3 has a mobile platform (end-effector) connected by 4 cables at upper locations (B_1), (B_2), (B_3) and (B_4). *Figure 2* shows only (B_1) to simplify. The cables can be reeling or unreeling through reels with step motors positioned inside of the fixed beams. The variables to be controlled are X, Y and Z displacements (3DOF) and there are not rotations. The vectors and dimensions shown in *Figure 2* were used for the formulation of the kinematics equations. The vector $o\vec{A}_1$ in *Figure 2* represents the position of point (A_1) expressed at fixed frame {O}, like $o\vec{B}_1$ and $o\vec{P}$. The length of the cable from point (B_1) to (A_1) is the magnitude of vector $\overrightarrow{B_1A_1}$ and the vector $P\vec{B}_1$ represents the point (B_1) at the mobile frame {P}.

The method to measure the force in each cable uses a spring fix to a potentiometer (see the tension sensor in *Figure 3*). The spring is pulled or return at its free position while the step motor is reeling or unreeling the cable. The spring displacement "d" can be used with "k" factor and combined with potentiometer measures to calculate the force in each cable. The tension sensor assembly is connected to a microcontroller which reads the analog signal from the potentiometer and converts it to a digital value. The value represents the deformation of the spring that is sent to a microcontroller through a WiFi module (*Figure 3*).

To solve the kinematics, it is necessary to determine the length of each cable, i. e., the magnitude of $\overrightarrow{B_1A_1}$ shown in *Figure 2*. The length $(B_1)(A_1)$ is the vector magnitude $\overrightarrow{B_1A_1}$ and Eq. 5 is used for all cables. The length of each cable is calculated using the IK in the homogeneous transformation matrix from values of vector ${}^{o}\vec{P}$ of the end-effector. Eq. 6 is the Eq. 2 applied at the robot proposed in this work.

The normalized vector $\hat{S}i_{BA}$ is calculated by Eq. 7 and the wrench of the weight W is calculated from Eq. 2 and given by Eq. 8.}

$$(B_i)(A_i) = \overrightarrow{\|B_iA_i\|} \quad i = 1, 2, 3, 4 \qquad \text{(Eq.5)}$$

$$\$_i' = \hat{\$}_i \cdot F_i = \left[\hat{S}i_{BA}\ \overrightarrow{oB_i}\ x\ \hat{S}i_{BA}\right] \cdot F_i \quad i = 1, 2, 3, 4 \qquad \text{(Eq.6)}$$

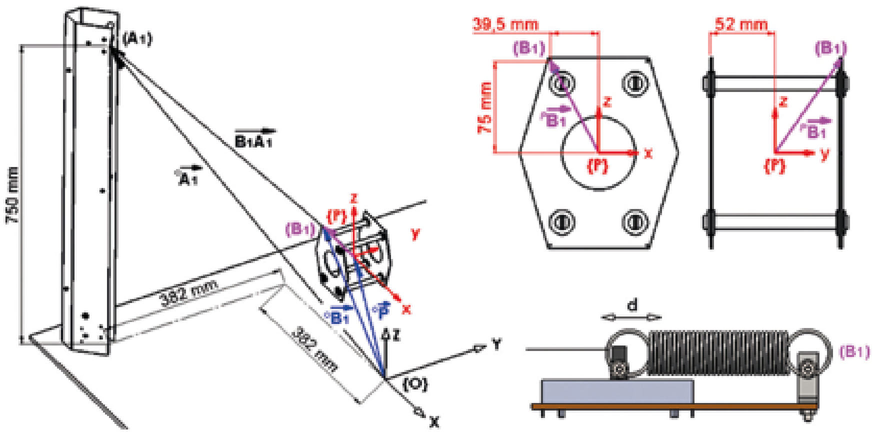
$$\hat{S}i_{BA} = \left[\frac{(o\vec{A}_i - o\vec{B}_i)}{\overrightarrow{\|B_iA_i\|}}\right] \quad i = 1, 2, 3, 4 \qquad \text{(Eq.7)}$$

$$\$'_W = \hat{\$}_W \cdot W = [\ 0 \ \ 0 \ -1 \ \ \overrightarrow{{}^{o}P}\, x\, [0\ 0\ -1]\ ] \cdot W \qquad \text{(Eq.8)}$$

Where $[0\ 0\ -1]^T$ is the unit weight in the Z direction. The vector $\vec{S}_0$ is represented by vector ${}^{o}\vec{P}$ in Eq. 8 because ${}^{o}\vec{P}$ is also a vector that starts from the fixed origin {O} to the axis of weight application. Since each vector $o\vec{B}_i$ (i = 1, 2, 3, 4) and the wrench matrix contains the coordinates P_X, P_Y and P_Z in its structure then the linear system $\hat{\$}'_1 \cdot F_1 + \hat{\$}'_2 \cdot F_2 + \hat{\$}'_3 \cdot F_3 + \hat{\$}'_4 \cdot F_4 = \hat{\$}_W$ is solved if the values of P_X , P_Y and P_Z are known. It will result values for the forces and the lengths of the cables. On the other hand, if the force values are known then P_X, P_Y and P_Z can be found through an iterative method.

Figure 2

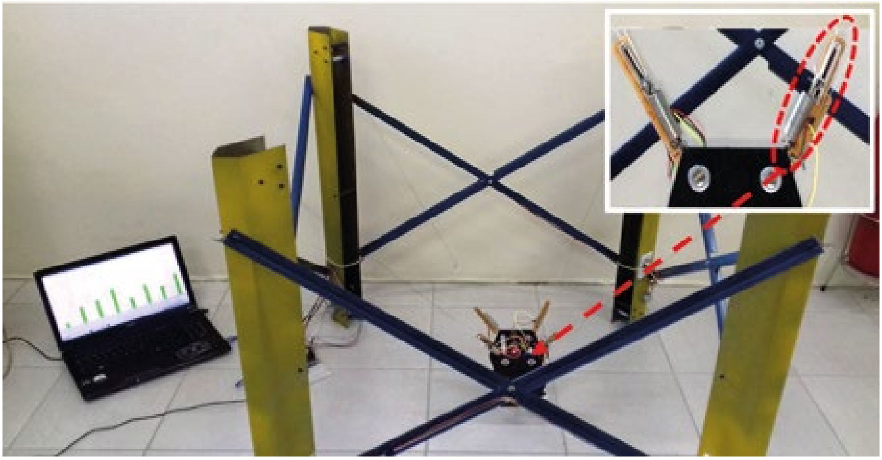
The 4-cable-driven parallel robot, end-effector and tension sensor



Source: Own elaboration

Figure 3

The 4-cable-driven parallel robot with end-effector, tension sensor and tension graphics



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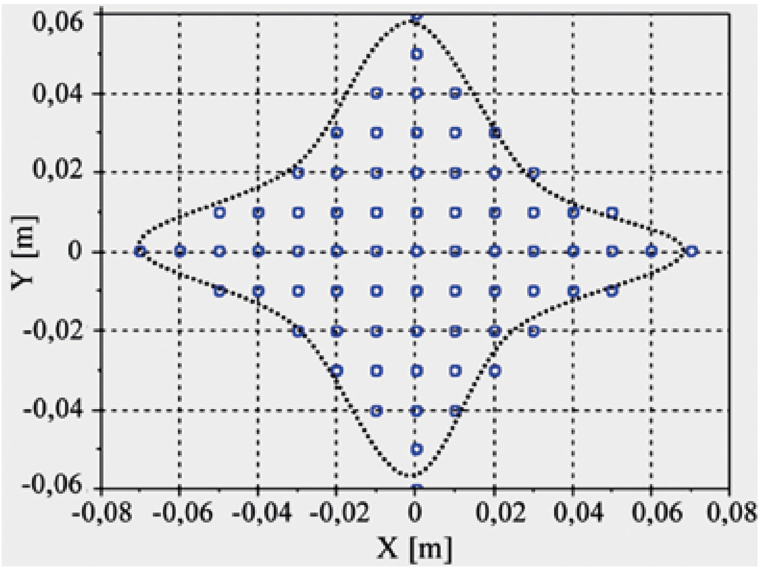
Results

Through the linear system, it is possible to calculate the values of the forces according to the location of the end-effector. Increments of 0.01m were given for the X, Y and Z axis. In the X axis the variation was from -0.05m to 0.05m, in the Y axis from -0.05m to 0.05m and in the Z axis from 0.00 to 0.03m.

The workspace was also limited to keep the tension of the cable in a positive range and below of $343 \cdot 10^{-2}$ N due to the linear measuring range of the potentiometer. *Figure 4* shows the XY workspace (top view) of the end-effector for all the angles equals to zero.

Figure 4

Workspace (top view) of the 4-cable-driven parallel robot



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Conclusion

The use of trigonometry to deduce equations for IK and FK in a cable-driven parallel robot is a time-consuming process. Screw theory can be implemented to find the equations of motions, forces and the workspace of a 4-cable-driven parallel robot with an organized and simplified system of equations.

Acknowledgements

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Comparison of fuzzy FPD+I and state feedback controller for a differential agricultural robot

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Abstract

Mobile robots are complex systems that assist one or more specific tasks. In the agricultural case, challenging environmental conditions affect movement and task performing. In this chapter, state feedback and fuzzy controllers were developed for Ceres -an agricultural robot with 200Kg of payload. Controllers were designed after a dynamical modeling stage using system identification techniques with open-loop data acquired from the real plant to refine the model parameters. The fuzzy controller is desired to obtain a faster response concerning classical controllers and to compensate nonlinear and/or unmodeled dynamics. To get a zero steady-state error, an FPD+I architecture was implemented. Simulations were performed, and a faster response was obtained with the fuzzy controller. Results have shown

a control signal according to the ranges used in the motor drivers embedded in the robot Ceres. Future works will integrate the fuzzy controller to the robot by using the Robot Operating System (ROS).

Keywords: Mobile robot, control, agricultural robot, fuzzy controller, feedback controller.

Introduction

Mobile robots are used to perform assistance tasks such as indoor guiding, payload movement, and recently, agricultural tasks [1]. However, agrarian field robots have an important lack compared to the high potential of this technology [2]. Environmental conditions, rough terrains, obstacles environment, and sloped terrains, are some of the challenges to develop such robots [3]. On the other hand, the growing food demand implies the need to increase the field size and crop productivity, while reducing agricultural costs [4]. The use of vehicles to assist tasks such as harvesting, weeding, fertilizing, and fumigating have obtained prominent results in different fields such as rice [5], citrus [6] and grapes [7].

Two main subsystems are required to obtain a useful robot to assist agricultural tasks. Firstly, a mobile platform that allows performing the job in the whole crop, with a localization system and guidance systems. The second subsystem is related to the primary purpose of the robot and can be tools for weeding, seeding, harvesting, sensing agricultural variables, or other tasks [8].

Mobility requirements must be able to control linear and angular velocities of the robot commonly named guidance, taking into account velocity limits, crop lines, and robot dynamics. Due to localization and path following requirements, the guidance performance needs to be assured. A complete hierarchy for an autonomous robot is described in [9].

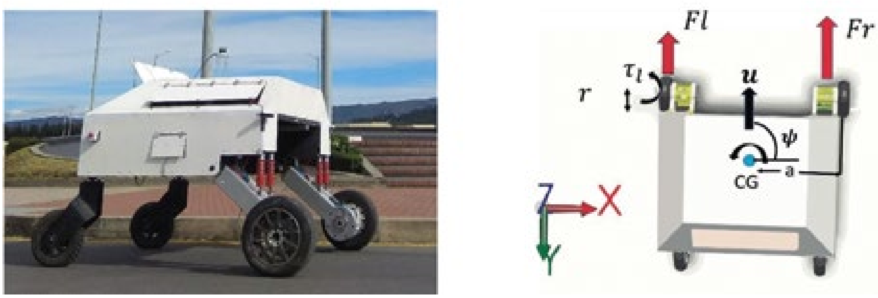
This work compares a state feedback technique and a fuzzy logic technique for guidance navigation for our 200 Kg payload capability - agricultural robot CERES. Some relevant approaches in the same directions are the agricultural low size tractor for visual navigation [10], a custom-designed robot for fertilizing potato fields [11] and a robotic platform for beets fumigation that achieved a 12 % of herbicides reduction [12].

Methods

We have designed our robot Ceres – Agrobot to face three agricultural challenges, i.e., weeding, fertilizing, and fumigating. A setup of three linear actuators is located in the bottom part of the robot with the farming tools. To move the robot across the crops, a differential locomotion scheme is used, with two brushless motors in the front part and two freewheels (castor wheel type) in the rear section. To increase the crop navigation performance, a high capability inertial measurement unity (IMU) is placed. The kinematic and dynamic analyses for the Ceres robot are carried out in this section. Then, control techniques are applied and compared to obtain the reference velocities.

Figure 1

Ceres robot



(Left): Agricultural robotic platform electrically powered with differential traction, a payload of 100 Kg of solid fertilizer, 20 liters for disinfecting purposes, and a weeding system. (Right): Principal forces of Ceres robot used for modeling purposes. Source: Prepared by the authors

Modeling

Navigation into the crops requires a low error system to preserve the field integrity and perform the necessary tasks. Such level of performance is why a conventional control process is done, including mathematical modeling of the robot dynamics, design, and simulation. This section tackles the robot two-stage modeling step.

First, kinematic analysis and then a dynamic analysis using the Euler-Lagrange approach [13] are performed. For this purpose, forces and dimensions are defined as shown in *Figure 1* (right). Considering $\dot{\theta}$ as the wheel velocity, a simplified model of Ceres robot is described by

$$\beta_{11}\ddot{\theta}_r + \beta_{12}\ddot{\theta}_r + \beta\dot{\theta}_r = \tau_r$$

$$\beta_{21}\ddot{\theta}_l + \beta_{22}\ddot{\theta}_l + \beta\dot{\theta}_l = \tau_l$$

Where:

$$\beta_{11} = \beta_{22} = \left[\frac{Mr^2}{4} + \frac{I_{CG}r^2}{4a^2} + I_{wheel}\right]$$

$$\beta_{12} = \beta_{21} = \left[\frac{Mr^2}{4} - \frac{I_{CG}r^2}{4a^2}\right]$$

Notice that no slip between the wheel and the ground is considered. Beta parameters are constant and only depend on robot physics. However, they contain uncertainties that need be reduced.

Physical parameters are obtained from the Ceres CAD model, where the materials and payload are taken into account. These parameters are mass $M=530Kg$, inertia at the center of gravity $I_{CG}=47*10^9\ Kg.m^2$, inertia at the wheel $I_{wheel}=219*10^6\ Kg.m^2$, distance from the center of gravity to each wheel $a=1,2m$, wheel radius $r=0,28m$ and an estimated friction β between the wheel and the specific terrain. To find the values of β_{xx}, and the coefficients in the previous equations, open loop data is captured in real tests over solid ground. Inputs (voltages to motor drivers) and outputs (velocities) are registered using ROS. In order to excite the system, pseudo-random binary signals are applied to the motors. Then, an algorithm of parametric estimation such as *Recursive Least Squares (RLS)* was applied. By several simulations with combinations of the obtained parameters we determine that the dominant dynamics of Ceres is related to β_{11}, β_{22}, while β_{12} and β_{21} are only the 13 % of the β_{11}, β_{22} value. These results mean that there are no couplings between right and left wheels.

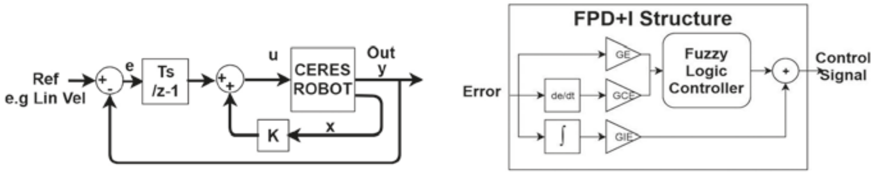
Finally, a similar identification process is performed to obtain a transfer function relating the voltage applied to motor drivers to the obtained torque (proportional to angular velocity). Besides, by using kinematics equations for wheeled robots, the linear and angular velocity of the robot is obtained from each wheel velocity.

Controller's design

To obtain an autonomous robot, we must design and implement controllers, including velocity controllers, path-following controllers, and a path-planning algorithm. This subsection describes the state feedback and fuzzy controllers designed for linear velocity and angular position, obtained by direct integration of angular velocity model, on Ceres robot.

Figure 2

Controller structure



(Left): State feedback controller structure. (Right): Fuzzy Logic controller structure. Source: Own elaboration

State feedback controller

The design of the first controller started from the state space model that can be viewed in *Figure 2*-left. In this scheme, the states are the linear velocity and angular position. Integral feedback is used to obtain zero steady-state error. As control objectives, a stabilization time of 5 seconds and a damping factor $\zeta = 0.9$ is defined according to the open-loop response obtained by applying steps to each variable in the real plant and measuring outputs with the embedded IMU. These objectives to achieve similar closed-loop behavior with low control effort. With the described requirements and to get a Hurwitz matrix, the closed-loop dynamic is established. To obtain small control efforts, the natural dynamics is taken into account to find the state feedback controller coefficients.

Fuzzy controllers

A vast number of architectures are used with fuzzy controllers to supervise, complement, or replace PID controllers. In this case, replacing the PID controller can improve the performance in several operating points in nonlinear systems [14]. However, in robotics, a low tracking error of the reference signal is required. This requirement is fulfilled typically with an integral gain. Besides, fuzzy controllers with integral action are challenging to design for an error input due to the uncertainty over the steady-state value, that affects assigning membership values [15]. To avoid the fuzzification process of integral error, an FPI+D architecture is chosen [16]. This structure attributes a fixed gain over the integral error which is added to the fuzzy control signal to obtain a zero steady-state error.

The membership functions at the input are selected triangular to obtain a lower computational time in the implementation stage. Moreover, input functions are designed to avoid overlapping of more than two membership functions. In that condition, a value can never be assigned to more than two groups. Finally, the center membership function is designed with a higher slope for the fastest rising time [15].

Then, a tuning process is performed starting by the gain conversion between a classical PID and fuzzy controller proposed in [16]. The control objectives are the same as in the state feedback design, i.e., a response time similar to the open-loop response (5 seconds) and a low signal to each wheel with non-reverse commands.

Results

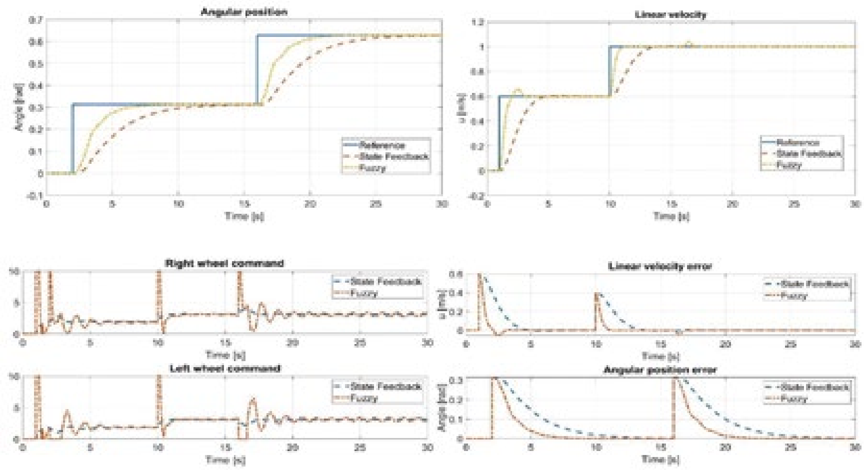
Simulations are carried out to compare the performance of the designed controllers with multi-step signals. This section compares and analyzes the results before a future integration stage to the Ceres robot.

After applying the fuzzy and state feedback controllers to the previous model, the results shown in *Figure 3* were obtained. *Figure 3*-upper left shows the angular position of the robot; here, the response of the fuzzy controller was approximately 5s faster than the reaction of the state feedback controller. On the other hand, *Figure 3*-upper right shows the linear velocity of the Ceres robot where the response of the fuzzy controller was 2s faster than the reaction of the state feedback controller. However, the former has some overshoots due to saturations of control signals, as shown in *Figure 3* (bottom left). The first overshoot at t= 2s occurs because of the saturation of the right and left voltage in motor drivers; the second overshoot at t= 16s is due to the saturation of the left wheel voltage applied to the motor (angular position reference). This saturation affects the linear velocity at t=16 because of the existing coupling between the dynamic model states.

It is important to remark that the angular velocities of the wheels are proportional to the input voltages, so the effect of the saturation of the motor voltages at the input of the motor drivers is reflected in the linear and angular velocities limitations. We use a saturation between 0 and 10 V. The lower limit was chosen not to have a reversal of rotation in the motors, while the upper limit considers the maximum limits of the motor drivers. Then, the control signals saturate when the amplitude of steps changes, i.e., when the control signal is at its highest value. Furthermore, bearing in mind that the fuzzy controller response is faster than in the state feedback, the control signal is stronger, as seen in *Figure 3* (bottom left). Finally, in *Figure 3* (bottom right), the control objective was achieved, i.e., an error in steady-state equal to 0, at the time of 5 seconds. Notice that the fuzzy control acted faster than the state feedback.

Figure 3

Comparison of the results obtained with the two types of control



(Upper left): Angular velocities. (upper right): Linear velocities.
(bottom left): Wheels commands. (bottom right): Velocities errors.
Source: Own elaboration

Conclusions

This paper summarizes two control techniques used to guide an agricultural robot that moves at a constant speed and the desired orientation. The dynamic model is described by the Lagrange approach. Identification techniques were applied to have a more accurate model. Considering two single-input single-output systems, the control techniques were developed. The first one was based on state feedback control, and the second one was based on fuzzy logic control. The fuzzy controller has an FPD+I structure based on the error and its derivative with an integral term added. The control law is given by the sum of fuzzy PD and integral contributions.

The fuzzy control manages to compensate for nonlinear dynamics or not completely modeled dynamics such that the controller's performance from a temporary response objective is improved. The controllers designed and the simulation tests show appropriate control signals and allow them to reach real robot movements.

Furthermore, path-following controllers will be designed to obtain a complete locomotion scheme that allows crop lines following from GPS coordinates.

Acknowledgment

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Sección II

Resúmenes extendidos

En esta sección se encuentra la información que respalda las ponencias realizadas en LACAR2019, en las que se presentaron resultados preliminares de proyectos de investigación y desarrollo tecnológico efectuados en distintas universidades de Latinoamérica.

A Vision-Based System for Evaluating the Quality of the Coloration of Thick Blood Smears in Malaria Diagnosis

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Keywords: Malaria, quality, diagnosis, automatic, thick blood smears.

Background, Motivation and Objective

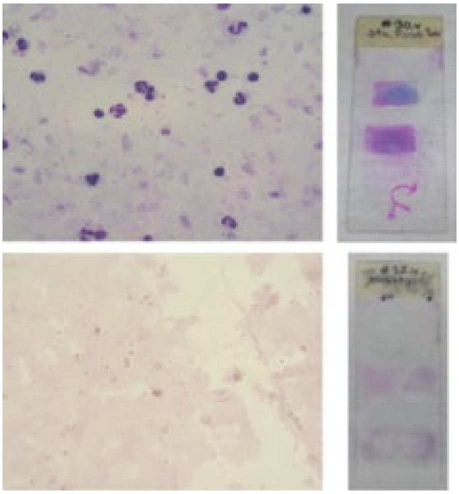
Malaria is an infectious disease and a serious problem of public health. In regard to Colombia, during 2018 a total of 62141 cases of Malaria were reported [1]. For carry out the malaria diagnosis, a blood sample is spread with square shape, above a smear. This technique is named thick blood smear and is the reference method chosen as first option for malaria diagnosis. This thick smear is dyed to allow the parasites visualization. The microscopic malaria diagnosis takes around 1 hour since the sampling to diagnosis statement. Additionally, 15-30 minutes more are required by the microscopist to analyze the smear. In published reports, the WHO has emphasized the need for all laboratories responsible for malaria diagnosis to fully comply with a strict inspection of the diagnostic techniques they implement to guarantee the correct diagnosis [2]. *Figure 1* shows an example of two blood smears (images in the second column), and their corresponding microscopic image (First column). The first row shows a properly stained smear. As a result, leukocytes and platelets are perceived. However, the second row shows an example of what is perceived when the staining process of the smear is not properly done; no leukocytes, neither platelets are visualized.

Taking into account the influence of the staining procedure in all the malaria diagnosis process, this project proposes an image analysis system for the automatic evaluation of the staining process, by analyzing the quality of the coloration of the thick blood smear. The system will automatically determine if the smear complies with the minimum requirements of quality to be analyzed by the microscopist, in terms of coloration stablished in WHO [2] and INS & MinSalud [3].

Image analysis in Malaria diagnosis has been studied before. However, to the author's knowledge, the evaluation of the staining procedure of the smear, which is crucial to ensure the visualization of the parasite by microscopy, has not been studied before by the research community.

Figure 1

Problems in the staining process of the smear



Note: First row shows the smear and its corresponding image when it is correctly stained. The second row shows a smear that was not properly stained (elements of interest are not visualized, e. g. no leukocytes, neither platelets). Source: Prepared by the authors.

Materials / methods

Samples donated by the Instituto Nacional de Salud are going to be used to develop the study. Images of the malaria parasites observed in the smears were capture with a Zeiss Scope A1 microscope equipped with a camera (same brand) and 1000X magnification lens (Centro Tecnológico de Automatización Industrial (CTAI) from the Pontificia Universidad Javeriana, Bogotá). First, an analysis of different color spaces will be carried out in order to determine the best color space that allows the detection of the interest objects and their separation with the background information. Then the coloration of the smear will be evaluated using the background information of the image. It will be obtained by image processing techniques such as, image thresholding.

Results

Preliminary analysis was carried out with manually selected smears with good and low coloration quality. The tests were programed using MATLAB (MATLAB® Student, R2018a, USA). A thresholding function was designed for evaluating visually the effectiveness of each color space separating elements of interest from the background. From the tests, it was found that the HSV and the RGBn color spaces allowed to obtain better results when applying the thresholding function. In particular, the GB component was the one that showed the best results, which confirms that the results reported in the literature for thin blood smears [4] are applicable to thick blood smears, as well.

Discussion and conclusions

In the normalized RGB color space, the observations for individual RGB components similar to declarations described for the separate components from HSV color space. In particular, the GB component showed a better distinction between background and the other components of the smear. Similar results have been reported by Rosado and collaborators [4] and Hedge and colleagues, too [5]. The results have been in consonance with current literature.

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A Deep Learning Approach to Detect and Classify Plastic Bottles for a Recycling Robot

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Keywords: Deep learning, classification and localization, cobots, plastic bottles, recycling.

Motivation

The PIR (Perception for Industrial Robots) project from the Pontificia Universidad Javeriana (PUJ) Bogotá, explores the use of robots for the waste classification tasks. As it is shown in *Figure 1*, this process implies repetitive and dangerous tasks for operators (e. g. they are expose to contaminated materials for long periods of time), and this is why the process needs to be improved soon. In [1], we introduced the plastic classification problem and we presented a strategy to integrate a dual-arm industrial robot for waste separation tasks. Now, in this work, we present the work that is being developed for improving the separation of plastic bottles using data driven approaches. Two well-known Deep Learning frameworks are being analyzed, the YOLO (You Only Look Once) [2] and Mask R-CNN (Region-Based Convolutional Neural Networks) [3].

Deep learning has been widely used for detecting people, cars, and other objects. In the case of recycling, in [4] the authors presented a CNN (Convolutional Neural Network) for classifying recyclable materials, called RecycleNet. The system was trained using images that correspond to waste samples encountered around one of the campus of Stanford University. With the proposed network, they obtained an accuracy of 90 %. Although deep learning approaches have been already implemented in the state of the art for waste classification tasks, to the author's knowledge, there have not been approaches proposed yet that investigate the classification of plastic bottles by their type (PET, COLOR HDPE and WHITE HDPE).

Figure 1

Manual plastic classification at the Alqueria Recycling center in Bogotá, Colombia

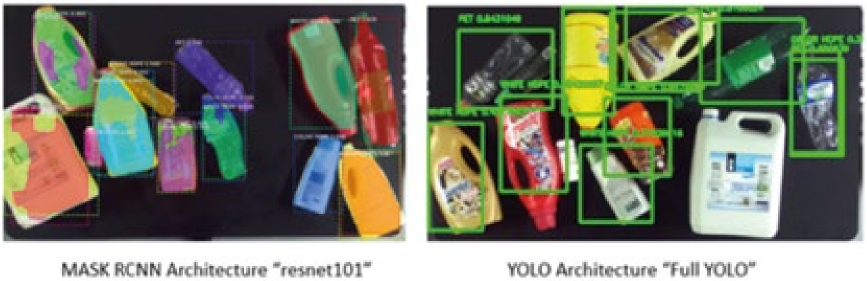
Source: Prepared by the authors based in pictures from Alqueria Recycling Center

Results

The waste classification testbed is comprised of a robot, a worktable, a camera, and classification bins. The system runs based on open-source software (ROS, ROS-I, and OpenCV). For the development of the deep learning algorithm, a dataset of 1300 images that contains plastic bottles, was created. Bottles in the images were manually labeled using the VIA 2.0.5 tool [5]. Labels correspond to 3 categories: PET, WHITE HDPE, AND COLOR HDPE. The dataset was divided for training (70 %), validation (20 %), and test (10 %). With that information, two well-known deep learning algorithms YOLO and Mask-RCNN were trained, and their results were compared. *Figure 2* shows an example of the obtained results. The left image corresponds to the Mask-RCNN results, and the right image corresponds to YOLO. Table 1 summarizes the results a video is found in [6].

Figure 2

Results using Mask-RCNN and YOLO



Source: Own elaboration

Table 1

Summary of the detection and classification accuracies for Mask-RCNN and YOLO

Framework	**Architecture**	**PET [%]**	**WHITE HPDE [%]**	**COLOR HPDE [%]**
Mask RCNN	Resnet101	60	70	70
YOLO	Full YOLO	55	65	65

Source: Own elaboration

Discussion and conclusions

Both networks were trained with their default parameters. Based on the results, the best accuracy for classifying plastic bottles was obtained with Mask-RCNN. In the case of YOLO, the overall accuracy was smaller; however, it is important to highlight that YOLO is known as a real-time framework, and therefore inference time was shorter. Preliminary results show us that the networks present problems classifying PET bottles, especially in images with reflections. Additionally, the labels of the bottles can interfere the classification process. The latter can be solved improving the dataset including, if possible, samples of all the possible bottles available in the market. Current work is focused on integrating the network with the robot and on tuning the networks in order to find their optimal parameters for the task. Additionally, the dataset will be extended.

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Diseño de una unidad de investigación sobre tecnologías de paneles fotovoltaicos en la región centroamericana

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Resumen

En la actualidad existen grandes avances en el desarrollo y rentabilidad de fuentes de energía amigables con el medio ambiente. Las Energías Renovables no Convencionales (ERNC), especialmente la eólica, la fotovoltaica y la biomasa, ya alcanzaron un grado de madurez y competitividad que las hace cada vez más viables y aptas para potenciales clientes e inversionistas. Todo lo ya logrado en Costa Rica, permite definir objetivos ambiciosos en materia de ERNC, y proponer así una hoja de ruta viable, sin muchos sobresaltos para toda la región, donde se permita un desarrollo o crecimiento integral con el uso de estas fuentes. Es relativamente fácil desde el Instituto Costarricense de Electricidad, seguir liderando el desarrollo con ERNC a nivel regional, con los beneficios económicos que ello implique; sin embargo, con la Energía So-

lar Fotovoltaica se encuentran distintos grados de avance en cuanto a su desarrollo, uso e implementación a nivel nacional.

Por esto, se planteó la necesidad de realizar un estudio sobre la eficiencia y el comportamiento de las diversas tecnologías aplicadas para el desarrollo y construcción de Plantas Solar fotovoltaicas. Esto puntualizará los criterios y tendencias que permitirán asegurar las actuales y futuras inversiones, orientar a nuestros clientes internos o externos hacia soluciones más rentables o eficientes, según lo requieran; y así, procurarle el máximo beneficio, con una visión competitiva, bajo condiciones estables. Esto es así porque no solo basta con usar tecnologías; es también importante evaluar cada dispositivo o parte, investigando su potencialidad, sus características y su uso convencional, de manera que al instalar y monitorear su comportamiento, se pueda constatar o verificar, paso a paso, su eficiencia y rendimiento, adaptabilidad al medio ambiente, "tropicalización", y evaluación o diagnóstico de cada parte o componente deseable.

Las pruebas y experimentos realizados resultaron exitosos, creíbles y muy concluyentes respecto del comportamiento de cada panel solar fotovoltaico. Se pudo asegurar la certeza de los datos de placa de cada fabricante, verificando una muy acertada clasificación y trazabilidad de los datos. Esto asegura a quien desee adquirir a futuro paneles de las marcas evaluadas, que la seguridad de lo que adquieran ha pasado por pruebas exitosas en condiciones tropicalizadas.

Palabras clave: Energía solar fotovoltaica, panel fotovoltaico.

Introducción. La energía solar fotovoltaica

A mitad del siglo XX, se introdujo un proceso de producción de cristales de silicio de alta pureza que aceleró el desarrollo de la energía solar fotovoltaica. Con el correr de los años la eficiencia de estos ha ido en aumento [1]. Para los años 70 del siglo pasado, Ingenieros de la Administración Nacional de la Aeronáutica y el Espacio (NASA), desarrollan el primer panel solar fotovoltaico para aplicaciones terrestres. Mientras que las primeras inspecciones y análisis del rendimiento o comportamiento de paneles solares fotovoltaicos se realizaron en celdas prototipos, por tratarse de ejemplares casi únicos que sirvieron para identificar los parámetros y variables más significativas del proceso solar fotovoltaico. En estas etapas de la investigación solar fotovoltaica, siempre estuvieron involucrados especialistas de NASA, del Laboratorio Nacional de Energía Renovable de EEUU (NREL), y algunas universidades que luego se encargaron de formar grupos y asociaciones especializadas en el tema solar fotovoltaico, tales como: la Plataforma Solar de Almería (PSA) en España [2]; el Laboratorio Solar de Odeillo, en Francia; o el Internacional Solar Energy Research Center Konstanz (ISC), en Alemania.

Según informes de la organización ecologista Greenpeace, la energía solar fotovoltaica podría suministrar electricidad a dos tercios de la población mundial hacia el año 2030 [3]. Igualmente, es importante el buen uso del “software” o de instrumentos del “hardware” que procuren elevar el rendimiento de cada panel, y los índices para todo Sistema Solar Fotovoltaico [4]. Así, a continuación (en la sección 2) se presenta la caracterización de paneles solares fotovoltaicos, describiendo cómo mejorar el rendimiento de un panel. Las secciones 3 y 4 tratan acerca de la metodología y los modelos conceptuales, respectivamente. Luego, en la sección 5 se presenta el desarrollo del banco de pruebas, y en la sección 6 un breve análisis de los resultados. Por último, las conclusiones.

Caracterización de paneles solares fotovoltaicos

Los ensayos en sitio de planta y bajo condiciones reales del campo, así como las fallas y daños típicos en los paneles solares fotovoltaicos; contribuyen a mejorar el rendimiento o la funcionalidad, al igual que el grado de tolerancia en diferentes condiciones de ambiente para cada panel. Requieren de monitoreo y observación durante un periodo adecuado, para determinar con precisión los efectos relacionados con los fallos detectados. Los resultados obtenidos sirven para perfeccionar ensayos ya existentes, acondicionar las normas de los diversos productos, fomentar el desarrollo de nuevos estándares y facilitar la evaluación exhaustiva de los defectos y daños encontrados en cada panel mediante la inspección y control de daños en cada sitio solar fotovoltaico. A nivel de laboratorios especializados encontramos dos tendencias: una como unidad móvil, denominada PV Mobile Lab; y otra que trata de una instalación fija, como las que se encuentran, por ejemplo, en la Universidad Adolfo Ibáñez en asociación con el Grupo AEOSOL New Energy S.A. de Chile, y en la Universidad Católica de Chile. Cabe aclarar que en Latinoamérica existen más laboratorios como estos; los hay en Argentina, Brasil, Colombia y otros, pero se hizo referencia a los chilenos, ya que ellos han llevado vanguardia en la región respecto al desarrollo de la energía solar fotovoltaica.

Metodología y actividades para la selección

Este documento corresponde, en parte, a una propuesta de proyecto; pero igualmente, es el resultado de una investigación mixta que combina varios métodos: una investigación cuantitativa, haciendo análisis por tendencia y estadística de datos ambientales y del proceso de conversión solar fotovoltaico; y también cualitativa, con base en el conocimiento y descripción de los diferentes tipos de paneles solar-fotovoltaicos y su comportamiento respecto a otros tipos de tecnologías aplicadas en su fabricación, según lo indicado por diversos centros de investigación, fabricantes y asociaciones para tales fines. Mediante una serie de tareas y actividades, se caracteriza al panel bajo condiciones reales de trabajo; se inspecciona con herramientas y procedimientos novedosos que requieren de una descripción y explicación correspondientes. Por tal razón, se emplea un tercer método: la investigación del tipo correlacional, descriptiva y explicativa.

También, se empleó un Sistema de Adquisición de Datos instalado en un Banco de Pruebas Solar Fotovoltaicas, (BPSFV) de la Planta Solar Miravalles. Importan las curvas de rendimiento reales y los valores de algunos parámetros y variables críticas, los cuales son indicadores de la calidad ofrecida por cada panel solar fotovoltaico para condiciones ambientales reales. En el momento de la elaboración de este documento, aún se estudian y analizan los resultados correspondientes al monitoreo y procesamiento en tiempo real, por lo que se espera que esto despeje ciertas dudas aún latentes que se refieren a la tropicalización de estas tecnologías.

Modelos conceptuales

La energía solar es una forma de energía, que se obtiene producto de las radiaciones electromagnéticas provenientes del sol, más conocidas como radiación solar. La cantidad de energía que nos llega desde el sol es tal que, si toda ella pudiera ser aprovechada, bastaría media hora de un día para satisfacer la demanda energética mundial durante todo un año [5].

La fuente de toda la energía del sol se encuentra en el núcleo, y esta se genera a partir de las fuertes reacciones nucleares de fusión, debido a las condiciones extremas de presión y temperatura que se dan allí. De esta manera, la energía de los rayos del sol se calcula mediante la siguiente ecuación de Planck: $E=hv$, donde **E**: energía de los fotones (partículas de la radiación electromagnética), **h** = constante de Planck= $6{,}625*10^{-34}$ Jules y **v** = frecuencia a la que oscilan los fotones o la frecuencia de las ondas de luz.

Otra expresión sencilla para el cálculo de los parámetros es: $\mathbf{I_{total} = I_{Directa} + I_{Difusa} + I_{Albedo}}$, donde: $\mathbf{I_{total}}$ es la radiación total solar incidente, $\mathbf{I_{Directa}}$ es Radiación solar directa incidente, $\mathbf{I_{Difusa}}$ es Radiación solar difusa incidente y $\mathbf{I_{Albedo}}$ es Radiación solar reflejada incidente. También es importante la potencia máxima que puede entregar el panel, P_{MAX}; la corriente de cortocircuito, I_{SC}; el voltaje de circuito abierto, $V_{OC;}$ y el factor de forma, definido como: $\mathbf{FF = PMAX / V_{OC} \cdot I_{SC}}$, donde I_{SC} es la corriente de corto circuito, V_{OC} el Tensión de circuito abierto, M_{PP} el punto de máxima potencia y I_{Pmax} la corriente de máxima potencia.

Todos los parámetros anteriores deben ser incluidos en una ficha técnica brindada por el fabricante de dicho panel, incluyendo características mecánicas, curvas, características V-I, y otros. Esta información es necesaria cuando se va a utilizar un panel dado, y así poder prediseñar el generador solar fotovoltaico requerido.

Conociendo los cuatro parámetros: Máxima Potencia **(P_{MAX}),** Corriente de Corto Circuito **(I_{SC}),** Voltaje de Circuito Abierto **(V_{OC}),** y Temperatura de Operación Nominal de la Celda **(T_{ONC})**; es suficiente para saber el comportamiento del panel en cualquier condición de operación definida por un valor de la irradiancia *G*, y un valor de temperatura ambiente *Ta*. Otro parámetro de diseño para el cálculo de una instalación solar fotovoltaica es la potencia pico Pmáx, que se define como la potencia máxima del panel en condiciones estándar de medida (CEM). Al conocer esta potencia y el área del módulo A, se puede hallar la eficiencia pico $\eta_{máx}$, o eficiencia del módulo en CEM.

$$\eta_{máx} = \frac{P_{máx\,CEM}}{G_{CEM} \cdot Area\ del\ Panel} = \frac{P_{máx\,CEM}}{1000\ ^{Watts}/_{m^2} \cdot A}$$

Desarrollo del Banco de Pruebas para la implementación del laboratorio solar fotovoltaico en Miravalles y Colorado de Abangares

Para proceder con la toma de datos, se ubicó en el laboratorio una serie de paneles solares fotovoltaicos de diferentes tecnologías. Luego, se realizó un monitoreo en tiempo real, durante las horas efectivas de radiación solar y por un periodo claramente establecido, mediante un procedimiento muy bien definido. En términos generales, este banco está provisto de dos sistemas SCADA, que servirán, sirven o han servido, en un caso, para almacenar y procesar los datos ambientales y meteorológicos; y en el otro, para almacenar y procesar los datos de las variables eléctricas, propias de cada panel solar fotovoltaico.

Para el desarrollo del primer experimento, se contó con dos bancos de prueba debidamente acondicionados e instalados en los sitios asignados previamente: Planta Solar Miravalles y Subestación de Energía de Colorado de Abangares. Estos Bancos de Prueba se acondicionaron con todos los equipos, la instrumentación, el hardware, el software y las condiciones adecuadas para realizar las mediciones y pruebas necesarias, requeridas para culminar con éxito el experimento que se desarrolla.

Luego de analizar los pros y los contras de varios métodos empleados por la mayoría de los fabricantes de paneles solar fotovoltaicos, en el Laboratorio Solar Fotovoltaico del Grupo ICE se decidió la realización de una serie de mediciones y pruebas durante todo un año, para caracterizar, identificar y verificar las propiedades reales de cada panel solar fotovoltaico ya escogido. La calidad de la medición dependerá de la precisión durante la medición simultánea de la producción de energía eléctrica, y de la radiación electromagnética en cada panel bajo pruebas. Cabe añadir que, para hacer el estudio comparativo de todas las tecnologías involucradas, se empleó lo que se denominó el "Diseño del Experimento", un procedimiento que se desarrolla a partir de la metodología propuesta.

Aspectos metodológicos

Con los instrumentos de medición necesarios, se midió la radiación solar incidente sobre los paneles correspondientes, bajo condiciones ambientales semejantes, así como las demás variables de interés. En cada panel fotovoltaico, se recolectó una serie de datos que sirvieron para su respectiva caracterización; los datos medidos se guardaron segundo a segundo en el *datalogger* respectivo de cada proceso, hasta acumular los datos requeridos para completar toda la muestra.

La muestra definitiva dependió del universo de datos y del tamaño de la población de interés, cumpliendo con todos los requerimientos y normativas previstas para tales propósitos. Con los 60 días requeridos más significativos, se dio inicio al estudio de todas las demás variables de interés, y así también se conoció su comportamiento para cada uno de los días específicos y para cada uno de los 10 paneles, (5 móviles y 5 fijos). El estudio solamente considera los datos que registre cada variable, segundo a segundo, desde las 5:00 a. m. hasta las 7:00 p. m. de cada día ya seleccionado, según el criterio de selección preestablecido. Finalmente, se procede con la elaboración de un informe descriptivo, claro y concluyente, sobre los resultados obtenidos.

Conclusiones

Se ha diseñado un centro de pruebas para realizar estudios sobre la eficiencia y el comportamiento de las diversas tecnologías aplicadas para el desarrollo y construcción de plantas solares fotovoltaicas; igualmente, se elaboraron los procedimientos, experimentos, formatos y metodología necesaria para la realización de pruebas y validación. Cada dato obtenido de variables y parámetros de cada panel solar fotovoltaico involucrado, fue registrado y luego estudiado su comportamiento en el dominio del tiempo. Esto sirvió para confirmar el comportamiento de cada parámetro y variable dentro de los rangos o variabilidad preestablecidos por cada fabricante, lo cual nos permite confirmar la certeza de los datos de cada uno. Cabe señalar que los paneles analizados y medidos se comportaron dentro del rango aceptable, según los datos de placa de cada fabricante.

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Diseño e implementación de un sistema de control para el proceso de deshidratación de cárnicos

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Palabras clave: Deshidratación de cárnicos, control Fuzzy.

Antecedentes, motivación y objetivo

El origen del proyecto nace de la necesidad de la empresa Carnes Frías Enriko de abastecer a un nuevo mercado con un producto saludable en forma de snack, que no necesite refrigeración y sea fácil de llevar. Gracias a un estudio y la inversión necesaria para lograr técnica, logística y materialmente el producto, el resultado fue el de kábano deshidratado en forma de snack. Así, después de estudiar a conciencia los datos obtenidos por los cuartos en donde se deshidrata el producto, se identificó la posibilidad de acelerar el proceso de obtención del mismo, manipulando algunas condiciones ambientales de manera controlada.

El beneficio primordial de esto es de tipo económico, ya que, si se acelera el secado, se obtiene producto más rápido y el cuarto de deshidratación se puede llenar con otro lote, llegando así a los índices de productividad esperados y, posiblemente, sobrepasándolos.

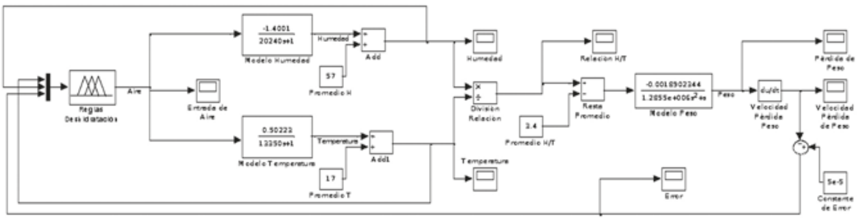
Metodología

Para el diseño del sistema de control, fue necesario establecer una relación entre las variables que intervienen y afectan directamente el proceso a controlar mediante la recolección de datos de las mismas. Para este proyecto las variables que afectan directamente el producto son la humedad (%RH), la temperatura (T), la velocidad del aire en el interior del cuarto de deshidratación (m/s) y la actividad de agua (%AW), que se mide directamente en el producto. Así, se estableció teóricamente una relación proporcional entre actividad de agua y peso del producto, definiendo entonces a la variable “peso” como salida del sistema y a las demás variables como entradas.

Al haber identificado las entradas y salidas del sistema de control, se procede al análisis de los datos previamente recolectados para entender cómo se relacionan las entradas del sistema con la salida y, de esta manera, definir que el control *Fuzzy* es el adecuado para lograr el objetivo final del proyecto: acelerar la curva de secado o deshidratación. La *Figura 1* muestra el modelo obtenido por identificación del sistema y que sirvió para validar, mediante simulaciones, el buen desempeño del controlador *Fuzzy* diseñado.

Figura 1

Modelo matemático que representa la dinámica del proceso de deshidratación de cárnicos



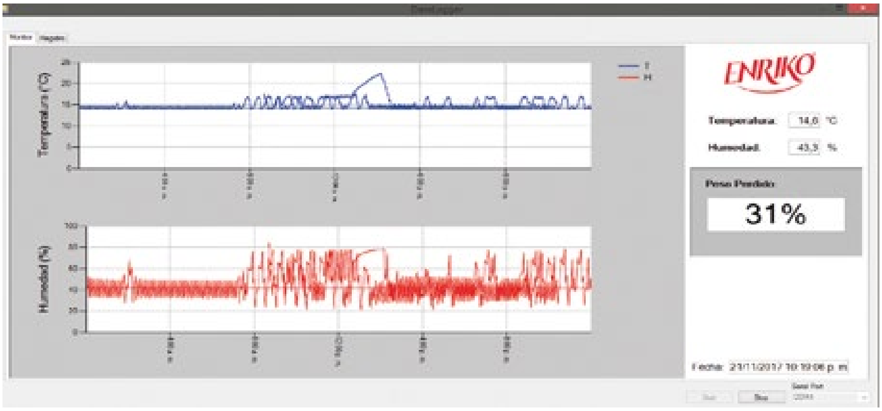
Fuente: Elaboración propia

Resultados

Los datos obtenidos con las simulaciones demostraron que se podía obtener una deshidratación exitosa en un menor tiempo. Dadas estas condiciones, se procedió a implementar un prototipo de prueba utilizando sensores de temperatura y humedad, un microcontrolador, un deshumidificador, una nevera y algunos ventiladores que funcionaron como actuadores. También se diseñó también el software para mostrar el comportamiento de las variables en el tiempo (cuya interfaz se puede observar en la *Figura 2*), mostrando que en un lapso de 38 horas llega satisfactoriamente al porcentaje de pérdida de peso deseado (31 %), reduciendo el tiempo de deshidratación en 14 horas.

Figura 2

Comportamiento de la temperatura y la humedad relativa en el interior del prototipo de prueba utilizado, durante un ciclo de deshidratación



Fuente: Elaboración propia

Todo el estudio sirvió para que la planta realizara ajustes en el diseño del cuarto real de deshidratación, realizando una implementación parcial en la que se ajustó la recirculación del aire y se implementaron inyecciones variables de aire frío y caliente, con el fin de emular el comportamiento del controlador *Fuzzy*. Los resultados fueron evidentes, reduciendo los tiempos de deshidratación de 52 a 38 horas, obteniéndose así un beneficio económico considerable al contemplar los tiempos de proceso que se tenían previamente; además del hecho de que no hubo necesidad de implementaciones costosas en hardware ni software.

Discusión y conclusiones

Los estudios acerca de la deshidratación en cárnicos y embutidos son escasos; por ello, para la realización del proyecto se requirió el empleo de técnicas empíricas que se fueron ganando a partir de la experimentación con el producto (kábano). Desde el punto de vista general del proyecto, se logra de manera satisfactoria disminuir tiempos de proceso con el control de las variables, generando un margen de utilidad mayor para la empresa en la que se hizo este estudio. Así, se evidenció que se puede construir un sistema de control manteniendo un bajo presupuesto, ya que con el uso de un microcontrolador de gama baja y un módulo de relés se puede implementar un controlador difuso robusto que ayude a resolver un sistema de control complejo; y que al realizar la implementación a nivel macro, no necesite contar con herramientas costosas. Simplemente se puede realizar una aproximación generosa entre el prototipo y la realidad, logrando mejoras considerables que se ligan a márgenes de utilidad más grandes para las compañías, disminuyendo costos de implementación y de proceso.

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Simulación dinámica de un sistema de control de movimiento con motor síncrono de imán permanente

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Palabras clave: Control de movimiento, conmutación senoidal, PWM, relación de inercia.

Antecedentes, motivación y objetivo

Se tienen aplicaciones de control de movimiento con servomotores en las cuales no se logra hacer la sintonización, dando como resultado movimiento irregulares con variaciones continuas de velocidad, hasta que el control genera el disparo de alarmas y detiene el movimiento del mecanismo o robot. Una de las causas posibles es la incorrecta relación entre la inercia de la carga reflejada en el eje del motor y la inercia del rotor del motor. Ante esto, el presente documento muestra el avance del trabajo realizado como proyecto de grado, en el cual se evalúa, mediante simulación, el efecto que tiene la relación de inercia en el comportamiento de un sistema de control de movimiento. La primera fase del proyecto se centró en la elaboración de un modelo matemático del sistema de control de movimiento, y realizar su respectiva simulación en lazo abierto. Así, se presenta el modelo matemático establecido y el modelo en bloques de Simulink®, herramienta de software usada para la simulación; y los resultados de las simulaciones en lazo abierto bajo diferentes condiciones de funcionamiento, así como algunas conclusiones respecto al comportamiento del modelo.

Materiales y métodos

En primer lugar, se revisó la información del servomotor disponible (Yaskawa SGMAH-04AAF41) y se encontró que el motor es de tres fases, síncrono de imán permanente. Se realizó una revisión bibliográfica para identificar modelos matemáticos del sistema con este principio de funcionamiento, y se seleccionó el modelo descrito por las siguientes ecuaciones [1]:

$$u_d = R_s i_d + \frac{d}{dt}\left(L_d i_d + \psi_f\right) - p\omega_m L_q i_q \tag{1}$$

$$u_q = R_s i_q + \frac{d}{dt}\left(L_q i_q\right) + p\omega_m\left(L_d i_d + \psi_f\right) \tag{2}$$

$$Te = \frac{3}{2} p \psi_f i_q = K_t i_q \quad (3)$$

$$\frac{d}{dt} \omega_m = \frac{1}{J} (T_e - T_l) \quad (4)$$

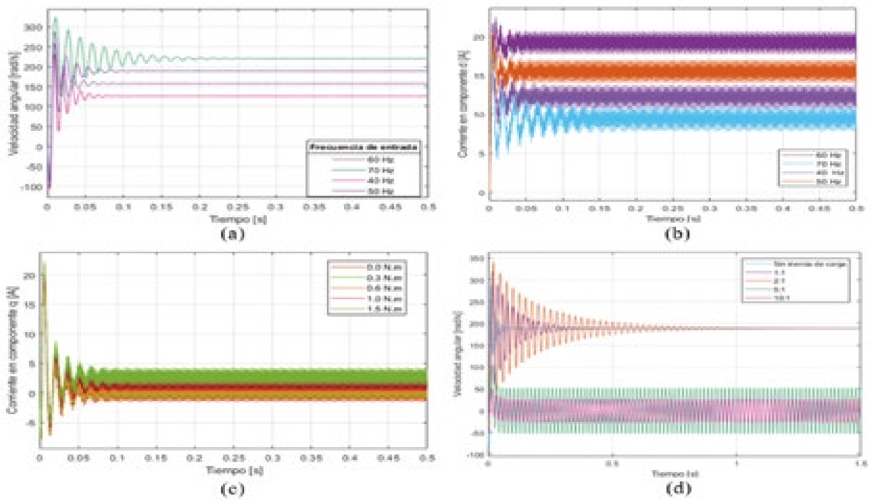
Posteriormente, se utilizó el bloque de simulación "Permanent Magnet Synchronous Machine" disponible en Simulink®, el cual incluye estas ecuaciones en su modelo interno. Además, se utilizó un modelo de inversor PWM senoidal [2] para generar la señal de entrada al modelo.

Resultados

Se realizaron varias simulaciones con diferentes frecuencias de entrada, para confirmar la relación frecuencia – velocidad de salida en el modelo. En la *Figura 1.a* se observa una oscilación transitoria en la respuesta, la cual es de mayor duración a medida que aumenta la frecuencia de entrada. Adicionalmente, en la *Figura 1.b* se aprecia que este aumento en la frecuencia de entrada tuvo como efecto una disminución en la componente de la corriente.

Figura 1

Resultados de simulaciones en Simulink®



Fuente: Elaboración propia

Por otro lado, se evaluó el comportamiento al aplicar un torque de carga. Según la ecuación (4), para que la velocidad angular se estabilice es necesario que el torque electromagnético del motor se iguale al torque de entrada. Este comportamiento se evidencia en la componente *q* de la corriente (*Figura 1.c*), la cual tiene una relación directa con el torque electromagnético (Ecuación 3). Finalmente, se realizó una variación en el parámetro de inercia, el cual es la suma de la inercia del rotor del motor y la inercia de la carga reflejada en el eje del motor. Se probaron diferentes relaciones de inercia (J_{carga}/J_{rotor}) y ser observó que a medida que aumenta la relación, el componente oscilatorio de la respuesta de velocidad aumenta (*Figura 1.d*). Sin embargo, a partir de la relación 5:1 el comportamiento se vuelve oscilatorio alrededor de los 0 rad/s.

Discusión y conclusiones

Se simuló y comprobó el modelo matemático del motor síncrono de imán permanente en el software Simulink®, y se analizó el comportamiento de este ante diferentes condiciones, variando la frecuencia del voltaje de entrada, el torque aplicado al rotor, y la relación de inercia entre la carga y el rotor. Estos resultados permitirán continuar con el diseño y simulación de un controlador en lazo cerrado de velocidad y confirmar el efecto de la relación de inercia sobre la estabilidad de la velocidad en el sistema y que permita diseñar controladores para sistemas con una relación de inercia alta.

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Diseño e implementación de un sistema neumático de compresión intermitente para tratamiento de isquemia en extremidades inferiores

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Resumen

El sistema cardiovascular permite que nuestro cuerpo obtenga los nutrientes y el oxígeno necesarios para el correcto funcionamiento de todas nuestras funciones biológicas, pero existen patologías como las isquemias que ponen en riesgo la vida de las personas al impedir el flujo de sangre oxigenada a los tejidos. En Colombia, en 2016 el 7 % de la población general padecía esta condición, siendo afectados el 39 % de los adultos mayores. Para ello, existen tratamientos invasivos como las cirugías, pero también hay alternativas como los dispositivos de presión neumática intermitente que, aunque actualmente se encuentran en el mercado, aún no son utilizados masivamente. Así, se describen aquí los resultados preliminares de un nuevo método que busca, a través de un

prototipo de laboratorio, imitar la irrigación sanguínea por medio de la retención programada de presión en cavidades neumáticas. Cabe mencionar que la siguiente etapa de este proceso de desarrollo tecnológico será la realización de pruebas clínicas, que están por fuera del alcance de esta primera etapa.

Palabras clave: Sistema cardiovascular, isquemia, irrigación sanguínea, dispositivos neumáticos.

Introducción

En nuestro organismo, el sistema cardiovascular se encarga de entregar nutrientes y oxígeno a todas las células del cuerpo [3]. Una de las patologías presentes en este sistema es la isquemia, que es una condición que impide la irrigación de sangre oxigenada a órganos y tejidos, los cuales con el tiempo empiezan a deteriorarse a tal grado que terminan muriendo [2] y los pacientes pueden correr el riesgo de perder alguna extremidad. La solución actual a esta patología incluye tratamientos invasivos, como lo son medicamentos anticoagulantes o las cirugías vasculares. En los dos casos se corren altos riesgos sobre la salud del paciente; esto es, hemorragias internas o deterioro de los vasos sanguíneos. Según el estudio realizado por Londoño y Duque en 2016 [1], en Colombia ha aumentado la prevalencia a sufrir isquemia, pues afecta al 7 % de la población general y el 39 % de los adultos mayores.

Teniendo en cuenta lo anterior, se diseñó un sistema de carácter no invasivo para ser utilizado sobre el sistema cardiovascular de la pierna, para ejercer una presión media-alta de manera gradual desde el pie hacia la rodilla, trabajando sobre los vasos sanguíneos alrededor de la tibia y la planta del pie. El objetivo principal del proyecto es la concepción, el diseño y la construcción de un prototipo funcional de laboratorio, que permita validar el cumplimiento de las especificaciones y requerimientos provenientes de un profesional de la medicina especializado en el tratamiento de este tipo de patologías. Vale la pena mencionar que esta etapa del proyecto no incluye pruebas clínicas con pacientes.

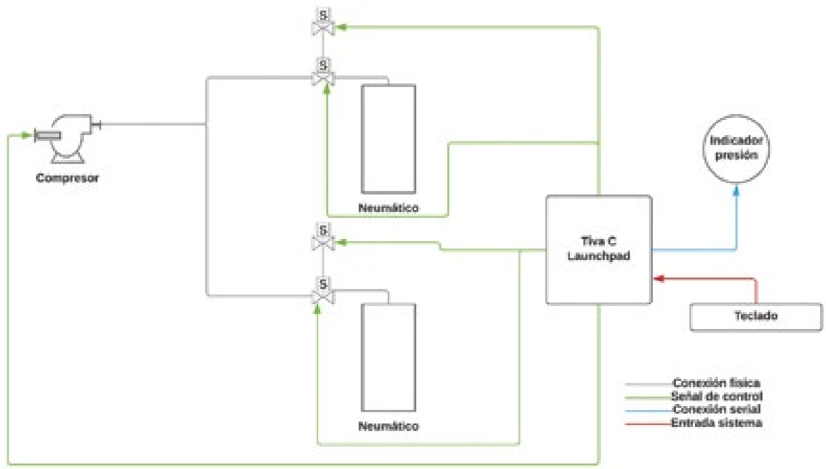
Metodología

A partir de la necesidad planteada por un profesional de la medicina, cuya especialidad es la cirugía vascular, se propuso el desarrollo de un dispositivo capaz de simular la presión ejercida por los músculos sobre los vasos sanguíneos en orden a restablecer el flujo de sangre oxigenada hacia tejidos afectados. Posteriormente, se procedió a hacer una revisión bibliográfica sobre diseños y pruebas médicas de dispositivos neumáticos aplicados al sistema cardiovascular. Luego de una etapa de análisis se consideraron las funcionalidades principales, así como los requerimientos y sus especificaciones técnicas, con el apoyo de profesionales del área de equipos médicos de la Fundación Valle del Lili y de la Pontificia Universidad Javeriana Cali.

El prototipo que se diseñó cuenta con dos cavidades neumáticas que recubren la zona de la pantorrilla, las cuales se encargan de ejercer la presión establecida sobre las arterias tibiales. Esto es posible debido al vaciamiento de las venas tibiales, produciendo un aumento en el gradiente artero-venoso, lo que favorecerá el proceso de irrigación de sangre oxigenada hacia el tejido que lo requiera, evitando así un gasto cardiaco y cardiopatías adicionales. El dispositivo genera una presión alta, superior a los 150 mmHg, que se mantiene por cuatro segundos para luego liberar aire hasta mantener un nivel entre los 40 y 60 mmHg. Este proceso se replica en cada una de las cavidades existentes, según el tratamiento necesario de cada paciente. En la *Figura 1* se observa que adicional a las dos cavidades neumáticas, se cuenta con una unidad de procesamiento para el cual se hace uso del microprocesador Tiva C Launchpad TMC123; para el suministro de aire se hace uso del compresor P22O3R Oken Seiko. En cuanto a los sensores de presión, se seleccionó la referencia MP3V5050. Para activación de suministro de aire a las cavidades neumáticas se emplea la válvula de referencia ZHV-019.

Figura 1

Diagrama básico de tubería e instrumentación



Fuente: Elaboración propia

Resultados

De momento, se logra una calibración exitosa del rango de presión ejercida, llegando a un límite máximo de 250 mmHg con un error del 5 %. Para la activación de válvulas se decide utilizar un conmutador de alta velocidad con el fin de accionar el mecanismo de la válvula solenoide en un tiempo de 100 mS, hasta lograr una presión de estabilización de 55 mmHg. El sistema se ha diseñado para que el usuario pueda ingresar por teclado la presión pico de operación del sistema, así como el valor de estabilización posterior de la misma y el número de ciclos de presión necesarios, con lo que quedará establecido el tratamiento para cada paciente. Por medio de una pantalla LCD se tiene un indicador de la presión que se está ejerciendo; además, el sistema guarda un registro histórico de las condiciones de presión con las que se realiza cada tratamiento.

Discusión y conclusiones

En la revisión bibliográfica efectuada se encontraron dispositivos neumáticos comerciales cuya aplicación principal se establece en drenajes del sistema linfático, pero que han sido probados como alternativas de tratamiento a isquemias en extremidades inferiores. Los efectos de estos dispositivos son positivos en el restablecimiento del flujo sanguíneo hasta el tejido afectado; sin embargo, no se evidencia la posibilidad de ajustar algún perfil de presión que emule el funcionamiento orgánico del cuerpo humano. Para lograr un gradiente de presión que se asimile más al flujo natural, es necesario utilizar válvulas proporcionales, las cuales permiten un mejor control sobre el flujo de aire en las cavidades, ejerciendo un rango de presión que recorra las extremidades afectadas. Sin embargo, este tipo de actuadores aumentarían el costo final del sistema, por lo que se hace necesaria una evaluación de resultados médicos con el fin de saber si amerita el costo adicional del sistema.

Es necesario aclarar que en la consulta bibliográfica se determina que las terapias con sistemas neumáticos de presión intermitente solucionan momentáneamente las obstrucciones causadas por isquemias, pero esto no significa que sea una cura completa para esta patología. Es posible que algunos pacientes tratados con estos métodos necesiten nuevamente realizar este procedimiento en algunos años.

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Evaluación de técnicas de planificación de trayectoria para robots móviles en V-REP

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Resumen

Aunque la planificación de rutas es un factor clave en la robótica móvil, probar las estrategias en entornos reales es una tarea difícil. Las plantas virtuales representan uno de los instrumentos más versátiles en el proceso de enseñanza-aprendizaje de los sistemas de control, ya que suplen la falta de laboratorios costosos o plantas reales. Por ello, en este trabajo proponemos una plataforma de co-simulación usando el simulador 3D V-REP y Matlab para la evaluación de diferentes estrategias de planificación de trayectoria para un robot diferencial en escenarios con obstáculos. Los resultados se comparan calculando el rendimiento de los métodos en simulación y en el entorno virtual con un control cinemático para el vehículo, mostrando diferencias notables entre escenarios ideales y reales.

Palabras clave: Planta virtual en V-REP, función de potencial, algoritmos heurísticos, descomposición de celdas, planeamiento de trayectorias, robótica móvil.

Antecedentes, motivación y objetivo

Las plantas virtuales son entornos de experimentación basados en software, donde los usuarios pueden operar diferentes componentes gráficos que representan elementos de un modelo físico, de tal manera que el sistema emula estrechamente el rendimiento real de la planta [6]. Una plataforma ampliamente utilizada para implementar plantas virtuales es V-REP [1], que ha tenido un auge en muchas áreas de la simulación e investigación de ingeniería, alimentada por el avance de las tecnologías basadas en la simulación 3D y su relevancia en la pedagogía [2], [4].

La planificación de rutas es una de las tareas más importantes en el desarrollo de la robótica móvil; sin embargo, los laboratorios reales para probar el desempeño de diferentes estrategias son costosos y limitados en espacio, configuración y posibles vehículos. En este sentido, la plataforma de co-simulación propuesta en este trabajo permite a los investigadores diseñar en V-REP un amplio espectro de escenarios con obstáculos configurables ubicados en áreas grandes o pequeñas, para el funcionamiento de uno o varios vehículos con sensores a bordo o en el escenario. Luego, las estrategias de planificación se programan en Matlab utilizando la información del entorno (obtenida de los sensores en V-REP) y envían las acciones de control a los vehículos en V-REP para ejecutar las trayectorias.

Como contribución, el documento analiza el uso de la co-simulación para la planificación de trayectorias de un robot terrestre con cuatro métodos representativos de planificación de rutas (campos de potencial artificial, búsquedas heurísticas y estocásticas, y enrutamiento basado en gráficos) descritos en [3]. El rendimiento de cada estrategia se compara mediante la implementación de los algoritmos solo en simulación (condiciones ideales) y en la plataforma virtual (condiciones reales), señalando las diferencias sobre la eficiencia, las colisiones y la distancia final recorrida. Las restricciones físicas del vehículo y los obstáculos en la planta virtual representan un desafío para mejorar la aplicación real de las estrategias en robótica móvil con sensores integrados (por ejemplo, con odometría).

Materiales y métodos

Para ilustrar la implementación de planificación y el control cinemático del robot en V-REP a través de Matlab, se proponen tres escenarios con pasajes estrechos, trampas y asignación aleatoria de obstáculos para diseñar trayectorias óptimas entre puntos iniciales y finales fijos. El escenario está compuesto por un robot diferencial (Pioneer_p3dx) y varios obstáculos (cubos de diferentes tamaños) en un área plana de 10×10 m. En la simulación, se descuidan muchas dinámicas físicas; por ejemplo, se supone que el robot es una partícula sin fricción y con actuadores ideales. Sin embargo, en V-REP todas estas condiciones se tienen en cuenta para el robot diferencial con restricciones no holonómicas. En este caso, implementamos un controlador cinemático descrito en [5], usando transformaciones para obtener las velocidades angulares de las ruedas desde la posición angular del robot y la distancia deseada a la meta. La posición angular de las ruedas se mide por odometría (en V-REP), por lo que el control se basa en medidas locales, lo que aumenta la complejidad de la estrategia general de planificación de trayectoria.

Las estrategias para proporcionar los puntos de ajuste al controlador cinemático se basan en métodos de planificación de rutas bien conocidos, como la minimización de campos potenciales, la optimización del enjambre de partículas (PSO), la exploración rápida de árboles aleatorios (RRT) y la descomposición celular (CD) [3], que representan la mayoría de las metodologías generales para obtener rutas óptimas. Cada algoritmo se programa en Matlab con las condiciones del escenario y algunos índices de rendimiento como la distancia, el número de colisiones y el logro del objetivo final; los cuales se evalúan en simulación y con la planta virtual.

Resultados

Para el análisis de resultados de un caso en particular es necesario que los algoritmos estén adaptados para cumplir con dos requisitos principales: i) la seguridad de la ruta (libre de colisiones); y ii) la minimización de la distancia total, definida como la suma de las distancias euclidianas entre los puntos de control en cada iteración. Con los métodos ajustados para el escenario, el robot puede alcanzar la posición deseada. Sin embargo, el método RRT presenta varias colisiones debido a la cercanía entre los puntos de ajuste y los obstáculos para acortar el camino. Además, el método CD muestra algunas oscilaciones generadas por la saturación de los actuadores (motores en el vehículo), mientras que el método de campo potencial presenta la implementación más compleja, pero la distancia final más corta. Se presenta entonces una compensación para la estrategia PSO, donde la distancia es más larga, pero el costo computacional se reduce; también se analizan dos escenarios más con pasajes estrechos y arreglos de trampa de obstáculos para proporcionar más pruebas y comentarios concluyentes sobre el desempeño de las estrategias, así como las diferencias entre la simulación y el entorno real de co-simulación.

Conclusiones

Este trabajo presenta la implementación exitosa de cuatro métodos de planeación de trayectorias en un escenario construido en V-REP, donde se presentaron varios inconvenientes como las colisiones con los objetos, las oscilaciones en la trayectorias y errores en la odometría propios de un ambiente real. Además, se resalta que esta plataforma facilita el proceso de enseñanza-aprendizaje, permitiendo a las instituciones educativas usar diferentes plantas con la mayoría de las interacciones reales que, generalmente, no están presentes en las simulaciones de modelos.

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