Design of Haptic Interface with Relative Position Feedback and Data Deployment using IoT Modules

Alejandro Gálvez, Alberto Marroquín
Instituto de Investigación e Innovación en Electrónica
Universidad Don Bosco
Soyapango, El Salvador

Carlos Bran
Instituto de Investigación e Innovación en Electrónica
Universidad Don Bosco
Soyapango, El Salvador
cbran@udb.edu.sv

***Abstract*— With the improvement on the capabilities of the networks bandwidth, the use of man-machine interfaces for teleoperation has improved significantly, which enhances the development of haptic interfaces that allows to describe the geometry of movement and package it for distribution to remote monitors or other actuators that replicate the geometric position.**

This document proposes a solution of an inexpensive haptic device, governed by an "Internet of Things" module that facilitates the interaction of its geometry with any node connected to a global network on a P2M model.

"Denavit-Hartenberg parameterization" is used to obtain the direct kinematics of the haptic and an IoT embedded system, for signal processing and publication of the coordinates of the "end effector" in the cloud on a user interface of deployment.

***Keywords*—IoT, Denavit-Hartenberg, Teleoperation, Virtual Environment, Kinematic Chain**

I. INTRODUCTION

For multiple applications, each time it's more frequent the use of mechanical extensions that allow us to broaden the perception of the environment in which we work, give us feedback [1] or extend the reach of the mechanical operations globally on virtual environments.

Haptics (manual interactions with the environment) has been opening field since the 80's in research areas such as robotic control, virtual assembly, collision detection, rehabilitation, among other solutions found to academic and commercial level. [2][3]. Among commercial haptic interfaces, there are devices with single application, such as Virtua IV [4], which is a device designed to perform virtual phlebotomy, or "FingerSight" that transforms a visual environment into one of sensations [5].

On the other hand, there are multipurpose devices, such as "Geomagic Touch" (Fig. 1) which provides a three-dimensional input with force feedback and integrate the sense of touch to research and commercial applications, as well as 3D modeling systems.

Fig. 1. Touch (Omni) 3D stylus

All commercial devices are ideal for research, however are closed designs, with little ability to upgrade or modification and also expensive.

A haptic device must have two fundamental characteristics: the ability to measure positions / forces of the user's action and the possibility of deploying or communicate these variables, for applications such as tele-operation that extends the sensitivity of the person, for decision making and the ability to interact with remote devices [6]; There are different types of teleoperation: bilateral, shared and semiautonomous [7]; this work focuses on the bilateral, which is based on time continuous signals of each joint of the mechanical interface, which can establish the geometry and path of motion. Fig. 2 illustrates teleoperation.

The teleoperated systems performance is based on "the notion of transparency." A system is "transparent" if the human does not distinguish between direct interaction and the tele-interaction with the remote environment [9].

The document is divided into 6 sections, first, the basic specifications for the controller and the characteristics of the IoT interface are described, then the concept and function design of the proposed prototype are detailed, the geometry of the interface, the equations governing the work-space, algorithms and finally implementation, testing, conclusions and recommendations are presented.

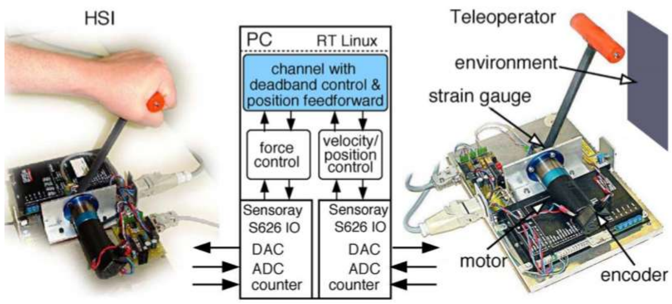


Fig. 2. To the left is the haptic interface, in the middle, the block describing the hardware that acquires and processes data to perform a control action on the teleoperator shown to the right [8].

II. INTERNET OF THINGS CONTROLLER

The evolution in the capacity of integration of transistors has allowed the development of more powerful embedded systems in terms of its speed and processing power, which in turn boosted a variety of low cost Internet of Things (IoT for their acronym) modules, which becomes in faster prototyping process of complete technology solutions with global connectivity [10].

One of the main considerations when designing controllers for IoT, is deciding which variables we will process locally and which variables globally; the computing in the fog (Fog Computing) [11] it's a model where it gets close the processing capacity of the critical components to sensors or actuators, to decrease the response time, on the other hand, the computing in the cloud (Cloud Computing) makes easier a more powerful processing in a globally distributed infrastructure, which by the nature of the Internet, could experience more delays for some real-time applications.

For the development of bilateral haptic systems [12], three conditions are critical: the first is the availability of channels of analog to digital conversion, with a sufficient number of bits for measurement accuracy, the second is the ability to process the direct kinematics arrays in fog or locally, and finally the ability to advertise the position variables to the cloud, for more complex processing or to interact with remote devices.

Spark Core [13] is a compact IoT module, with up to 8-ADC channel of 12-bit resolution, with STM32F205RGY6 ARM Cortex M3 processor at 120 MHz, capable of carrying the cloud up to 10 variables accessible on a REST architecture (REpresentational State Transfer), plus low power consumption and other general purpose digital lines or communication systems of local level as I2C or SPI; This platform provides all the conditions demanded by the system specifications.

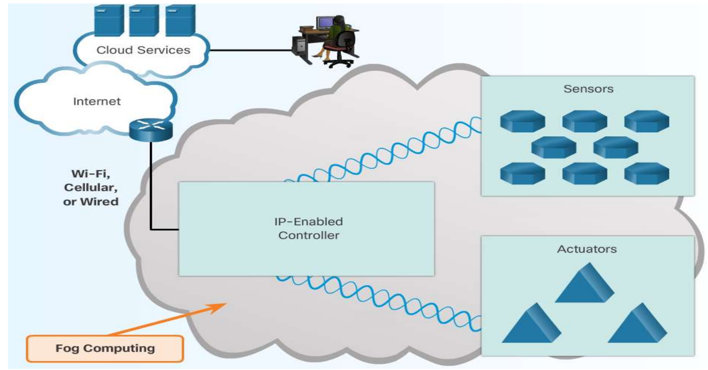


Fig. 3. Fog computing and interaction with cloud

III. SYSTEM DESIGN

A. Conceptual Model

The operation of the haptic system is based on two stages, which interact via web:

- The first one, is the processing in the fog, realized by the IoT module, which, from the voltage measurements of 4 potentiometers (SE1, SE2, SE3, SE4) located in the joints of the mechanical structure of the haptic device, angular displacements are obtained ($\Theta 1$, $\Theta 2$, $\Theta 3$, $\Theta 4$) in the links of it, and finally, by direct kinematics, calculates the relative position (Px, Py, Pz) of the "end effector" announced to the cloud.
- The second stage is local processing, which queries the cloud (cyclically) to verify the relative positions of the "end effector" of the structure and present them in a graphical interface.

The interaction between the two stages is shown in Fig. 4, in which the inputs and outputs with which the total system counts and data flow between the two sides are shown.

B. Functional Model

The functional model of the controller for processing in the fog is shown in Fig. 5, with the following blocks:

- Analog-Digital Converter (ADC): From the IoT module, 4 channels are used for 4 potentiometers located in the joints of the device, which by varying its angular position, generates variations in voltage; ADC allows to sample those variations, which are used as input data for the position calculus.

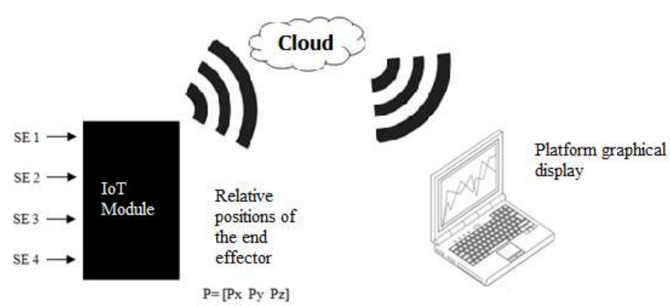


Fig. 4. Conceptual model for the haptic system

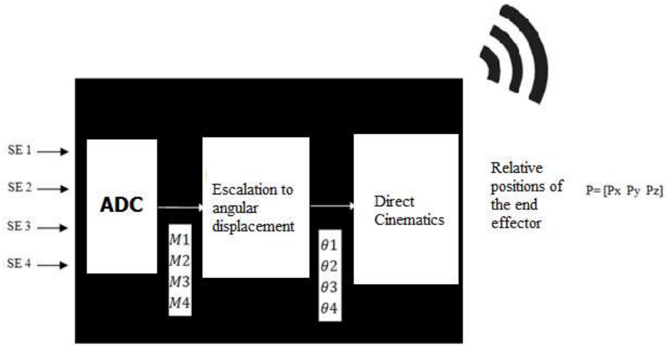


Fig. 5. Functional model for the haptic device controller

- Scaling to angular displacement block: After getting the ADC lectures, displacements are obtained by converting the analog reading to grades, obtaining: ϴ1, ϴ2, ϴ3 y ϴ4.
- Direct kinematics block: finally, from angular displacements, using direct kinematics, the relative position of the "end effector" of the haptic device Px, Py and Pz is obtained.

After this processing, the relative positions are sent to the cloud so that they can be consulted in real time from any node connected to the Internet.

IV. Geometry of the Haptic Interface

The proposed interface has the configuration of an anthropomorphic robot. This consists of an open kinematic chain, composed by of 4 rigid links with its 4 rotating joints (1DOF each). The links dimensions of interest of the haptic interface prototype are detailed in Fig. 6 Being the end effector the electronic pen used by the user, which, the cartesian coordinates of its tip, are feedback respect to the base of the link 1.

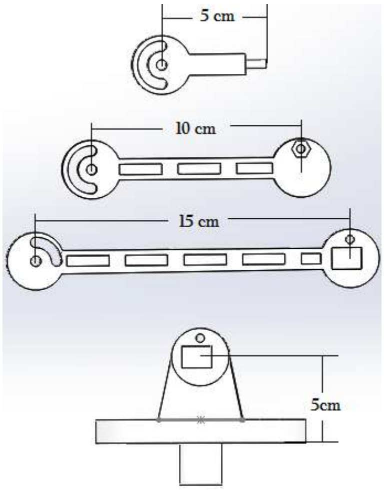


Fig. 6. Dimensions of the links 1,2, 3 and 4 (From bottom to top in the picture).

A. Direct Kinematics

To obtain relative Cartesian coordinates of the tip of the end effector of the haptic interface relative to a fixed reference frame in the support of it, is necessary to provide functions of the type:

$$x = fx\,(\Theta 1, \Theta 2, \Theta 3, \Theta 4) \quad (1)$$
$$y = fy\,(\Theta 1, \Theta 2, \Theta 3, \Theta 4) \quad (2)$$
$$z = fz\,(\Theta 1, \Theta 2, \Theta 3, \Theta 4) \quad (3)$$

Parameterization given by Denavit-Hartenberg [14] was used, with which it is possible to obtain the matrix of homogeneous transformation "T" that describes both: the rotation and translation of the tip of effector of the haptic interface, in terms of L1, L2, L3, L4, ϴ1, ϴ2, ϴ3 and ϴ4. To obtain DH parameters, it was used the Fig. 7, since the position shown (Home) denotes the angular values of 0° for the four joints. In addition, the positive direction of rotation of each joint and the frames of reference solidary to each link are shown.

The "T" matrix, that denote both: the rotation and translation of the framework, that is at the tip of the electronic pen, respect to the base of the link 1, is:

A04=

$$\begin{bmatrix} c(\theta 2+\theta 3+\theta 4)*c1 & -s(\theta 2+\theta 3+\theta 4)*c1 & -s2 & c1*(10*(\theta 2+\theta 3)+15c2+5c(\theta 2+\theta 3+\theta 4)) \\ c(\theta 2+\theta 3+\theta 4)*s1 & -s(\theta 2+\theta 3+\theta 4)*s1 & c1 & s1*(10c(\theta 2+\theta 3)+15c2+5c(\theta 2+\theta 3+\theta 4)) \\ -s(\theta 2+\theta 3+\theta 4) & -c(\theta 2+\theta 3+\theta 4) & 0 & 5-10*s(\theta 2+\theta 3)-15s2-5s(\theta 2+\theta 3+\theta 4)) \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

The haptic interface was designed to achieve the angular displacement of its four links, as follows (See Fig. 7):

$$\Theta 1 = [-90°, 90°]$$
$$\Theta 2 = [-90°, 0°]$$
$$\Theta 3 = [\,0°, 90°]$$
$$\Theta 4 = [0°, 90°]$$

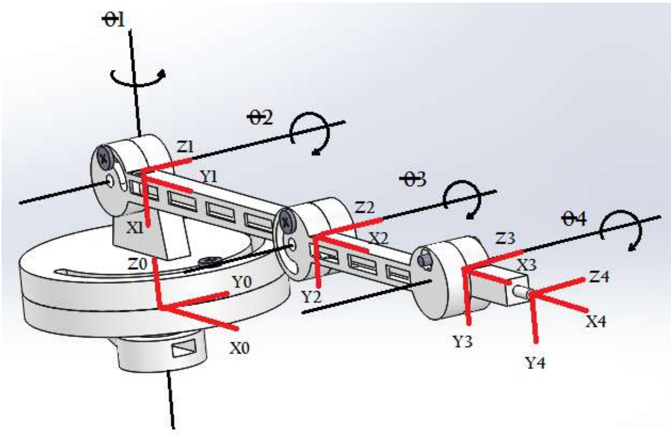


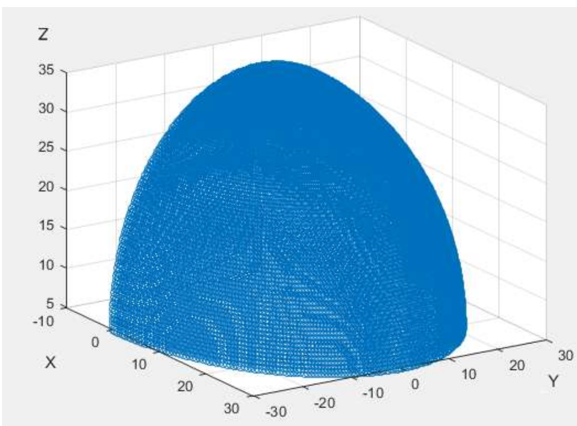
Fig. 7. Haptic device in "home" position for Denavit-Hartenberg parameterization.

B. *Work Space*

The virtual recreation of an environment, comprises a real work space, that is, a physical space where the tip of the end effector can move, that workspace, can be obtained theoretically performing an angular sweep of the joints, being the most representative, the sweep leaving joints 3 and 4 fixed, to obtain the boundaries of the workspace.

There is a mechanical limit for when the haptic interface be in a position of "home", cannot exist ϴ3 or ϴ4 movement, with the aim of achieving a workspace "about" ¼ sphere.

Evaluating in a cycle and in a nested form the angles ϴ1=[-90 °, 90 °], ϴ2 = [0 °, -90 °], ϴ3 = 0 ° ϴ4 = 0 ° with 1 ° increments, we obtain triads of Cartesian coordinates, which, when graphed generate the surface shown in Fig. 8.



g

Fig. 8. Matlab generated surface by sweeping the haptic device when is fully extended.

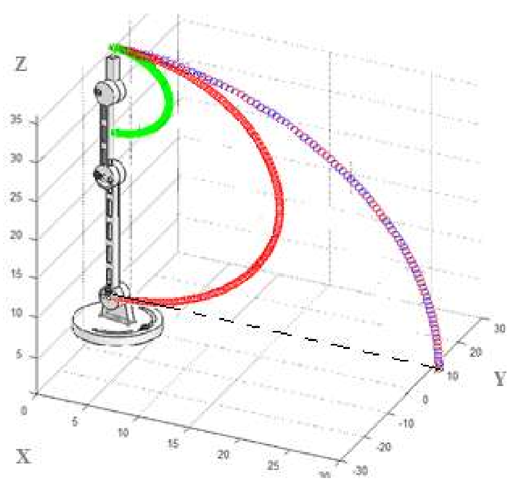


Fig. 9. Theoretical trajectories of the electronic pen's tip, evaluating kinematic equations in Matlab. Link 4 (green), link 4 and 3 together (red), links 4,3 and 2 together (blue).

Some trajectories of the electronic pen's tip are shown in Fig. 9, when the haptic device is initially in a vertical position (ϴ1 = 0 ° ϴ2 = -90 °, ϴ3 = 0 ° and ϴ4 = 0 °), for example: the trajectory shown in green represents the displacement of the link 4 (ϴ1 = 0 ° ϴ2 = -90 °, ϴ3 = 0 ° and ϴ4 = [0 °, 180 °]), the path shown in red represents the movement ϴ1= 0 °, ϴ2 = -90 °, ϴ3 = [0 °, 180 °] and ϴ4 = 0°. Finally, the path shown with blue color represents the movement ϴ1= 0 ° ϴ2 = [-90 °, 0 °], ϴ3 = 0 ° and ϴ4 = 0 °. As we can see, the paths shown are within the workspace of Fig. 8.

V. Implemented Algorithms in the Haptic System

A. *Algorithm for Capturing angular displacement of the haptic interface*

As described in the functional model of the controller, from measurements of the potentiometers of the joints of the mechanical structure and using the first three expressions of column 4 of the array (4), the system should be able to obtain the relative position of the end effector. To do that, the following algorithm has to be followed:

1. Individual reading of the 4 analog inputs (M1, M2, M3 y M4) of the IoT module ADC channels.
2. With the individual reading of the ADC channels, should perform scaling to degrees, in [0, 1023] range (10 bits' resolution) to [0°, 270°], which is the total displacement that is allowed by the potentiometers, obtaining the angular displacements (ϴ1, ϴ2, ϴ3 and ϴ4).
3. Using the angular displacement of the 4 joints, from direct kinematics and trigonometric operations, relative positions of the tip of the electronic pen in space (Px, Py, Pz) is obtained.
4. The controller updates the values of the relative positions of effector and publishes the results of the direct kinematics in the cloud for deployment or remote processing.

B. *Algorithm for graphical display of the Cartesian coordinates of the end effector in Real Time*

According to the conceptual model of the system, once the data is sent to the cloud, they must be read in order to represent them graphically, in real time:

1. Query to the network of cloud servers is performed, to acquire the relative positions obtained by the direct kinematics, made by the IoT controller.
2. Using the operating system console, a text file (.txt) is generated, where the result of the query is saved.
3. Using Matlab, the text file is read, and the data is stored in a vector.
4. Each vector element is associated with its respective coordinate (*x*, *y* and *z*).
5. To illustrate the point in a three-dimensional coordinate system, the axes are adjusted: *x*=[-30.30], *y*=[- 30,30] and *z* = [0,35].

VI. Implementation and Testing of the Interface

A. Construction of the Haptic Interface

The modeling of the interface was developed with Solid Works 2013, exporting the scheme to STL format for 3D printing. The mechanical design includes aspects such as: fixed structure while is not being manipulated by the user, easy assembly of the device and simple geometry.

All structure's parts are assembled by pressure or screws, in order to obtain adequate rigidity and minimum errors by lateral displacements of the joints.

The cables are passed by internal channels so not to obstruct the movement and facilitate the connection to the IoT controller.

B. Getting Cartesian Coordinates and Real Time Deployment in WEB Page

Because the relative position of the "end effector" is published in the cloud by IoT module, it is possible to make inquiries to obtain that information by any software for transferring files with URL syntax. For testing, a web page was implemented for real-time verification of the Cartesian coordinates of the end effector respect to its real position in the mechanical structure of the haptic system.

Using JQuery and JavaScript code, queries to the cloud are performed and the Cartesian coordinates obtained are updated on the web page, in Fig. 11 the coordinates of the pen's tip of the position of the interface, are shown in the web interface.

To evaluate the response time of queries from any node to the cloud, two tests were made over two networks: one for residential Internet service with bandwidth of 2 Mbps which average response time of the consultations was 6s, and another in a dedicated network with bandwidth of 30Mbps with an average time of 2.6s, which represent very good times because the IoT module don´t confined a dedicated VLAN.

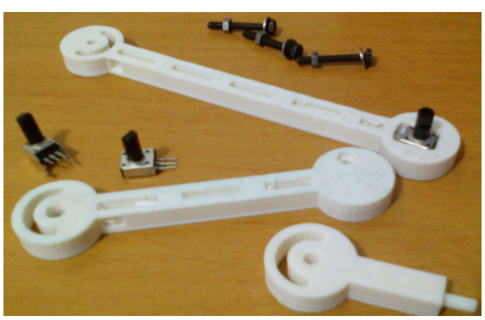


Fig. 10. Printed links 2,3 y 4, with their potentiometers and clamping screws not assembled.

Fig. 11. Verification of Cartesian coordinates in haptic device via web interface.

C. Real Time Graphic Representation of the Electronic Pen ´s Tip Trajectories

A sweep of the electronic pen was performed in order to obtain two significant traces for theoretical work space shown in Fig. 8. These traces are shown in Fig. 12. The trace resting on the XY plane due to the rotation of the joint ϴ1, moving in a range that the link its mechanically allowed: -90 ° to 90 °, while the other three joints remain 0 °. The trace resting in the XZ plane due to the rotation of the joint ϴ2: 0 ° to -90 °, while the remaining joints are 0 °.

In Fig. 13, the trajectories that were traced with the angular sweep made in Matlab (Fig. 9) are shown, but now drawn with the haptic interface built, overlapping dots on the traces is due to user manipulation, the precision of movement and speed of the network to which the controller is connected.

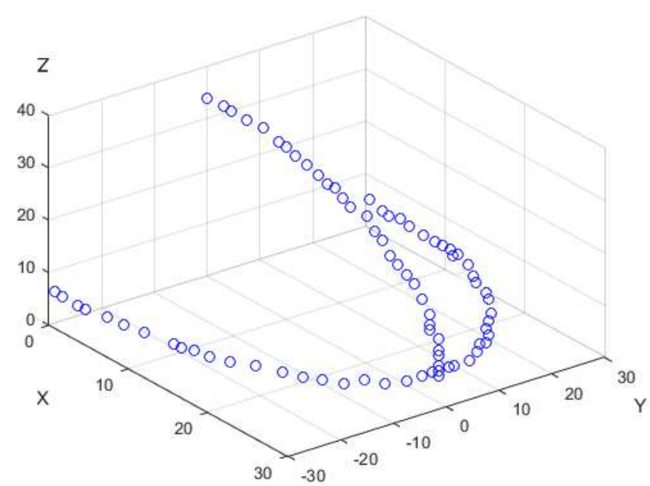


Fig. 12. Workspace representative traces of the haptic interface

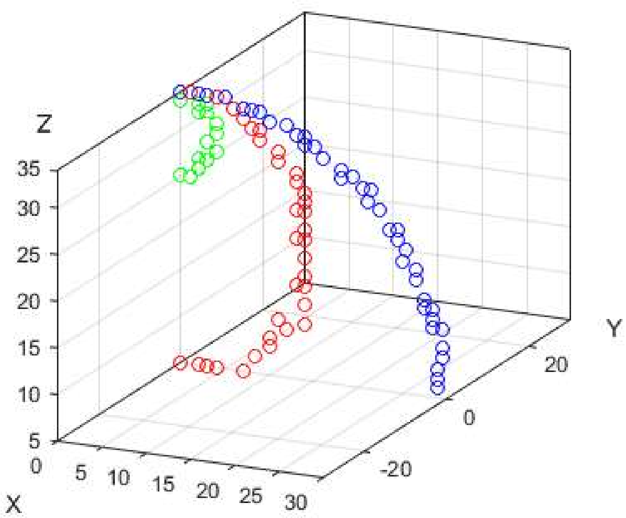


Fig. 14. Experimental trajectories of the pen tip deployed in Matlab. Link 4 (green), link 4 and 3 together (red), links 4, 3 and 2 together (blue).

CONCLUSION

According to the obtained results, the accuracy of the geometric location of the tip of effector doesn't presents noticeable differences with the results returned by the mathematical calculations, so that the prototype is a low cost alternative to commercial solutions.

The response times between the effector and the visualization remote display system is impacted by the visualization strategy that takes as reference a common reading file for two applications, so the delay is more penalized by this process than the use of the connection's bandwidth, on the other hand according to the recommendations of infrastructure IoT devices deployment, these go over separated networks and with particular bandwidth specifications and quality of service.

The force feedback process and positions replication of the haptic in a remote will be tackled future work.

The system's ability to publish variables to the cloud, allow more complex processing can be executed on this infrastructure, besides the data be used by more than one application.

REFERENCES

[1] Srinivasan, M A, Haptic Interfaces, In Virtual Reality: Scientific and Technical Challenges, Eds: N. I. Durlach and A. S. Mavor, Report of the Committee on Virtual Reality Research and Development, National Research Council, National Academy Press, 1995.

[2] What is Haptics? Available: http://www.geomagic.com/files/5613/4818/3863/what_is_haptics.pdf.

[3] Srinivasan, M A and Basdogan, C, Haptics in Virtual Environments: Taxonomy, Research Status, and Challenges, Computers and Graphics, Vol. 21, No. 4, 1997.

[4] El Virtual I.V. Available: http://www.laerdal.com/

[5] S. Horvath, J. Galeotti, B. Wu, R. Klatzky, M. Siegel and G. Stetten, "FingerSight: Fingertip Haptic Sensing of the Visual Environment," in IEEE Journal of Translational Engineering in Health and Medicine, vol. 2, no., pp. 1-9, 2014. doi: 10.1109/JTEHM.2014.2309343.

[6] T. Sheridan, BTelerobotics, [Automatica, vol. 25, no. 4, pp. 487–507, 1989

[7] Hirche, S.; Buss, M., "Human-Oriented Control for Haptic Teleoperation," in Proceedings of the IEEE, vol.100, no.3, pp.623-647, March 2012 doi: 10.1109/JPROC.2011.2175150

[8] Salisbury, J K and Srinivasan, M A, Sections on Haptics, In Virtual Environment Technology for Training, BBN Report No. 7661, Prepared by The Virtual Environment and Teleoperator Research Consortium (VETREC), MIT, 1992.

[9] S. Hirche, P. Hinterseer, E. Steinbach, and M. Buss, BTransparent data reduction in networked telepresence and teleaction systemsVPart I: Communication without time delay, [PRESENCE: Teleoperators Virtual Environ., vol. 16, no. 5, pp. 523–531, 2007.

[10] The Internet of Things (IoT) Overview, disponible en: http://www.internetsociety.org/doc/iot-overview

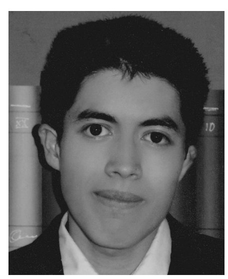
[11] Qué es el "Fog Computing" o computación en la niebla disponible en: http://www.cisco.com/c/dam/en_us/about/ac79/docs/IoE/IoE-AAG.pdf

[12] Emmanuel Nuño Ortega, Luis Basañez Villaluenga, "Teleoperación: técnicas, aplicaciones entorno sensorial y teleoperación inteligente", Universidad Politécnica de Catalunya, 2004

[13] Documentación de Spark Core disponible en: https://docs.particle.io/guide/getting-started/intro/core/

[14] A. Barrientos, *Fundamentos de Robótica 2° Ed.* España:S.A. McGraw-Hill/ Interamericana, 2014, pp. 97-99.

Alejandro A. Gálvez graduated from high school in Champagnat school, El Salvador, in 2011, obtained the graduate degree in English from the European Academy in 2009. He has received several courses such as: Auxiliary systems of internal combustion engines (Insaforp) in 2013, Diploma of photovoltaic systems in 2015 (Foundation Circe / UDB) online Courses Edx: "Thermodynamics (IIT Bombay)" and "Introduction to the computer science CS50 (Harvard University)". currently attends the 5th year in Mechatronics Engineering at Don Bosco University. Member of the IEEE and RAS chapter of robotics and automation. His research interests are heat transfer systems and haptic systems.



Alberto Marroquín graduated from vocational technical high school in electronics in Joyas de Cerén school, El Salvador, in 2011. He received the course "Introduction to the Internet of Everything" by Cisco in 2016, currently attends the 5th year in Electronics Engineering at Don Bosco University. Instructor of basic science and electrical school curses.

Carlos Bran: Director of the Institute for Research and Innovation in Electronics, Graduate Electrical Engineer, Graduate Technology Management, Master of Research in Information Technology and Doctoral studies at the Information Technology Research Center CITIUS. Work experience includes companies such as Dymel, Dynamo, AT&T, various companies in the area of telecommunications, Dean of the Faculty of Engineering of Don Bosco University, Director of Cisco Networking Academy Program, among others.
Professor of embedded systems, electronic design, computer networks and computer security, research interests include areas related to embedded systems, Internet of Things, ASIC design, communication protocols, parallel systems, energy harvesting and computer vision.