International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 18 (2018) pp. 13448-13453

PID Control of a Pneumatic Actuator for Waste Oil Flow on a Globe Valve

[1]Luis Carlos Ruiz, [2]Dario Amaya H, [3]Jorge Buitrago.

Engineering Faculty, Mechatronic Engineering Program, Universidad Militar Nueva Granada.

Abstract

The growth of the computational technologies as tool, had allowed design, build and implement, virtual scenes, where the user is immersed and then can interact with the objects, as is done in the real environments. In this work, it is exposed to the control of the fluid flow in the globe valve body with the pneumatic actuator. For this, its estimate the dynamic linear model of the mechanism, composed of the body valve and the actuator and in this way, design the linear control PID, adjusted to the regulation of fluid in the virtual process. This process, is directed to the student education in the trouble of a plant to control and then, conceive the importance to do this process to avoid to possible damages in the structure of the mechanism to control, as well, in the obtain of the desired products to offered in the market.

Keywords: dynamic model; PID control; damping coefficient; globe valve; pneumatic actuator; waste oil.

INTRODUCTION

The creation of virtual environments, in the present, has outstanding in the develop of scenes similarly to the real time [1], to give the opportunity to the person with physical disabilities or the human in general, to has access to places of difficult access or dangerous, as well, to access to places that due the rules of privates or states, does not allow. As result, is possible observe in the feedback of sensations that produce inside the environment. These feelings, is reflected in the natural behavior of the user [2], as show in entertainment areas in three-dimensional (3D) [3, 4], similarly in the education academy or in the industrial process execution, in scenes two-dimensional (2D).

Between the works developed, is the elderly rehabilitation, to restore balance and posture [5], Post-traumatic stress treatment (PST), to work in the emotional processing in adults directed to recovery of the child population suffering from abuse [6], as well as in cognitive recovery [7]. Other area that use de virtual environments, is the process to improve the methods of education and learning [8], which is use the information and communication technologies (ICT) [9]. As example, the scenes that use haptics feedback and intelligent systems, that is adjusted to the learn abilities of the students [10], as is developed in the elaboration of virtual practices to engineering students that allow conform and develop activities at global level [11, 12], as well the integration of technics as the augmented reality, to improve the human and machine interaction and give information associated with the objects located at real time [13, 14].

In the industry, has been developed virtual systems in areas as the architecture to observe the final finishes of the projects, the resource and the build process [15, 16], as well is observe in the integration of advertisements to promote the consumption of products as the cigarette [17]. In the tourist industry, was developed systems that give important information that require the user to obtain that he desire [18, 19]. The creation of this real immersive environments [20], was necessary obtain the mathematical models that correspond to the mechanism and it is possible the nature inside the scene, for this is obtain the use of technologies developed and used by the research and academic centers.

In this kind of industrial process, is possible use of process control, that in the same way is used to teach to the students to learn to estimate and manipulated the control coefficients with the intention of observe the process variation in the mechanism and obtain the desired results [21]. For examples, is the communication between mobile devices and the actuators, to do remote control, that not require the presence of the operator [22]. Finally, with results was obtained, coming in the industry with the internet of things, to obtain dynamic process, coupled the digital controllers and its corresponding algorithm [23], in devices of industrial use as the PLCs, to control of process and variables as the temperature, position, velocity, pressure, among others [24].

In this paper, is exposed the results that are generated in a virtual environment, which can observe the waste oil flow control in an oil refinement plant. The develop start with the obtaining of the dynamic model of a globe valve with pneumatic actuator for opening with air, which is in function of the stem position and the relation with the flow inside the valve. Then, the PID control is designed, to do the position control of the stem and finally estimate the coefficient of the control to obtain the desired results applied over the transfer function obtained of the valve. Finally, as conclusion, is proposed future scene industrial, that allow contribute in the academic training, as well, help in the industrial process supervision, remotely and locally.

METHODS

For design of the PID control of oil waste stream, is taken as an example the oxidation process of an oil refinery, as is described in **Figure-1**. In this picture, it is possible to perceive the loop control in charge of regulating the oil waste stream (CV-101) to the reactor, as well, the loop that controls the steam stream (CV-105) and oxygen stream (CV-104). To the oxygen and steam stream control, it is assigned the waste oil inlet to the reactor as the set point to each one, with the intention of adding the substances that requires the treatment of oil waste in the reactor.

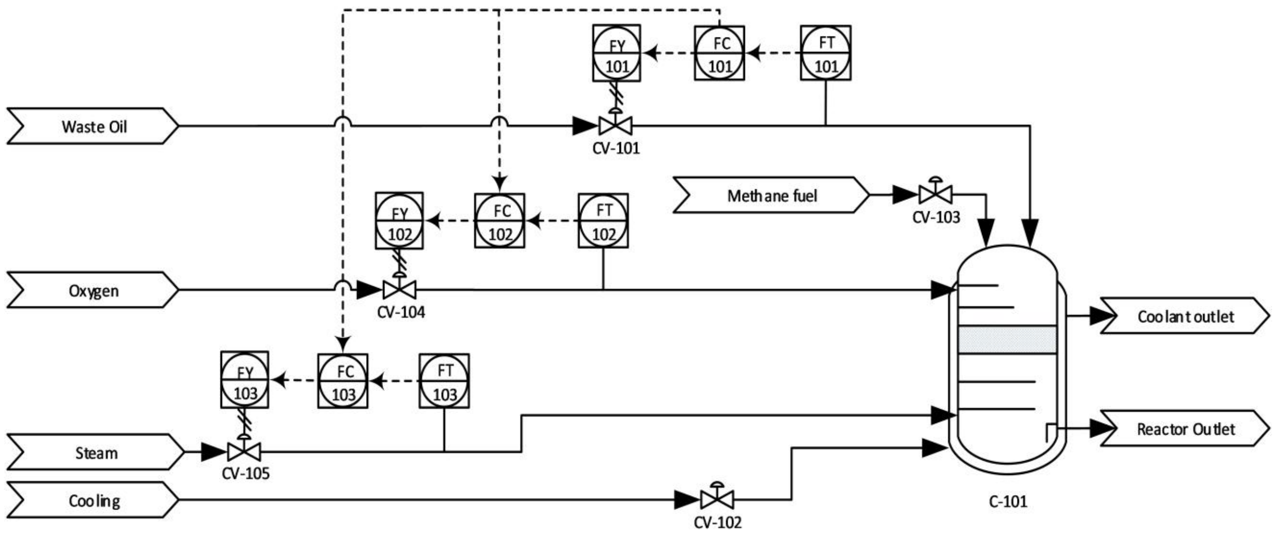

Figure- 1. Subproceso de oxidación en una refinería de petróleo, para tratamiento de residuos

To do the control is necessary indicate the actuators that are in charge of allow the regulation of each stream (oil waste, steam and oxygen), with the aim of obtain the characteristic equations that evidence the dynamic of the system and then ease the design of the PID control, to obtain the desired response to the entry to the reactor.

In this case, is proposed the use of the globe valves with pneumatic actuator AO (Air to Open), which change the fluid stream according to the stem position.

Dynamic model of a globe valve

To do the dynamic model of the valve, has in account the Figure-2, which show the cross-section of a globe valve with pneumatic actuator.

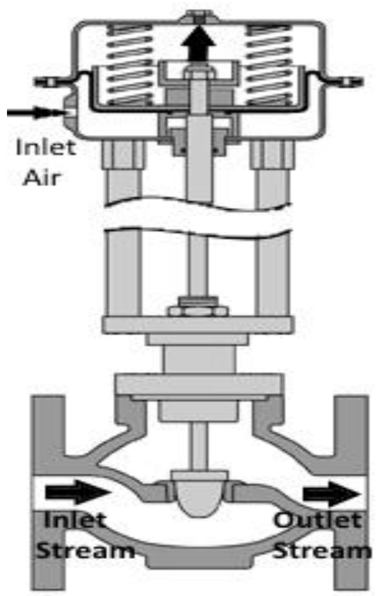

Figure- 2. Cross-section of a globe valve with pneumatic actuator

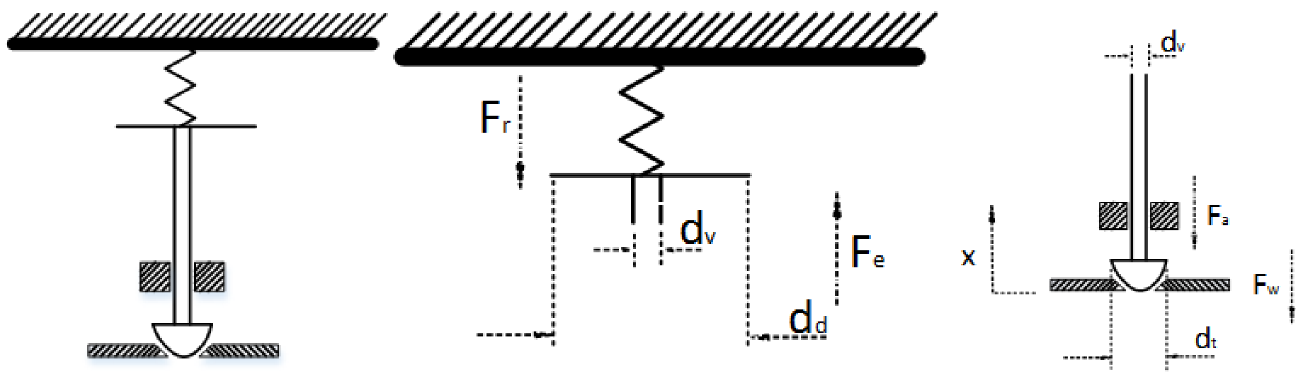

Figure 3. Force identification over the valve actuator.

First, is necessary obtain the characteristic equation of the valve actuator, for this, identify each of the forces that participate in the system, as show in the Figure-3. Then, the sum of the forces is realized, considering the system in equilibrium, as is described in the equation (1).

$$\sum F = 0$$
$$P_e * (A_d - A_v) = F_a + F_w + F_r \tag{1}$$

Where Pe is the thrust pressure over the diaphragm, Ad and Av, is the diaphragm area and stem respectively, the Fa, Fw and Fr, are the damping, weight and spring force respectively, that acts over the movement of the actuator stem. Each parameter, is replaced with the equivalent respect to the movement in *x,* as is show in the equation (2).

$$F_r = k_r * x(t)$$
$$F_a = c * \frac{dx(t)}{dt}$$
$$F_w = (m_v + m_t) * \frac{d^2x(t)}{dt^2} \tag{2}$$
$$P_e * (A_d - A_v) = (m_v + m_t) * \frac{d^2x(t)}{dt^2} + c * \frac{dx(t)}{dt} + k_r * x(t)$$

In this equation is appreciate the mv, is the stem mass, mt, is the plug mass, c and kr, are the damping and spring coefficient respectively. With this, is used the Laplace transform with the purpose of obtain the equation in the frequency domain, which is exposed in the equation (3) and then, obtain the transfer equation of the actuator.

$$\frac{X(s)}{P_e(s)} = \frac{A_d - A_v}{(m_v + m_t) * S^2 + c * S + k_r} = P(s) \tag{3}$$

The characteristic equation of the valve body, has in account the Figure-4, which explain the relation between the movement of the stem and the flow of the fluid.

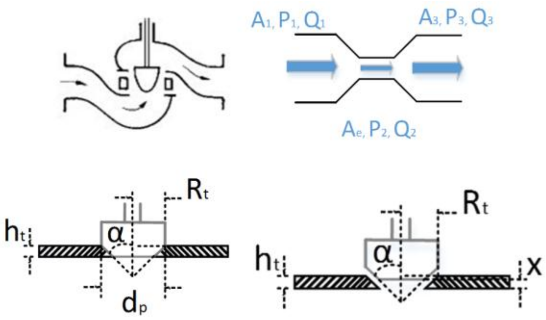

Figure 4. Relation between the movement of the stem and the effective area to allow the flow of fluid.

In this case is used the continuity equation of incompressible fluids to obtain the relation expressed in the equation (3), between the flow of the fluid (Q), the flux of the valve coefficient (Cv), the pressure fall over the valve (ΔPv) that is the difference between the pressure at the valve inlet (P1) and the pressure at the valve outlet (P2), finally is used the specific gravity (Gs).

$$Q = C_v * f(x)\sqrt{\frac{\Delta P_v}{G_s}} \tag{4}$$

Where f(x) is in function of the port area (Ap) and the effective area (Ae). Ae, correspond to the area that varies as the stem moves to allow the waste oil flow, as well the chamfer angle of the plug (α), the port height (h_t), and the advance of the plug (*x(t)*)

$$f(x(t)) = \frac{A_e}{A_p}$$
$$A_e = A_p - \pi * ((h_t - x(t)) * \tan(\alpha))^2 \tag{5}$$

Design of PID Control of a pneumatic Actuator

To design the PID control, is in account the Figure-5.

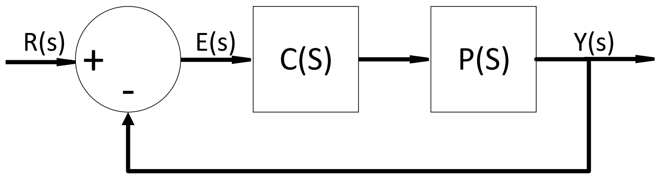

Figure- 5. Scheme of closed-loop control.

Which obtains the characteristic polynomial of the system, in charge of fixing the desired behavior, from the equation (6), with the gain proportional (Kp), integral (Ki) and derivative (Kd).

$$Pc(S) = 1 + C(s) * P(s)$$
$$C(s) = Kp + \frac{Ki}{S} + Kd * S \tag{6}$$

And to obtain de polynomial desired characteristics, is through the equation (7), due the increase of the system order, and is used the damping coefficient (ξ) and the non-damping natural frequency (ω_n).

$$Pd(S) = (S^2 + 2 * \xi * \omega_n * S + \omega_n^2)(S + 10 * \xi * \omega_n) \tag{7}$$

RESULTS AND DISCUSSION

To appreciate the control over the actuator, is proposed de Figure-6, as graphic programming of the system in the SIMULINK tool. In the same way, is has in account the values in the table 1, which is assigned to the constants at the equations (3) and (4).

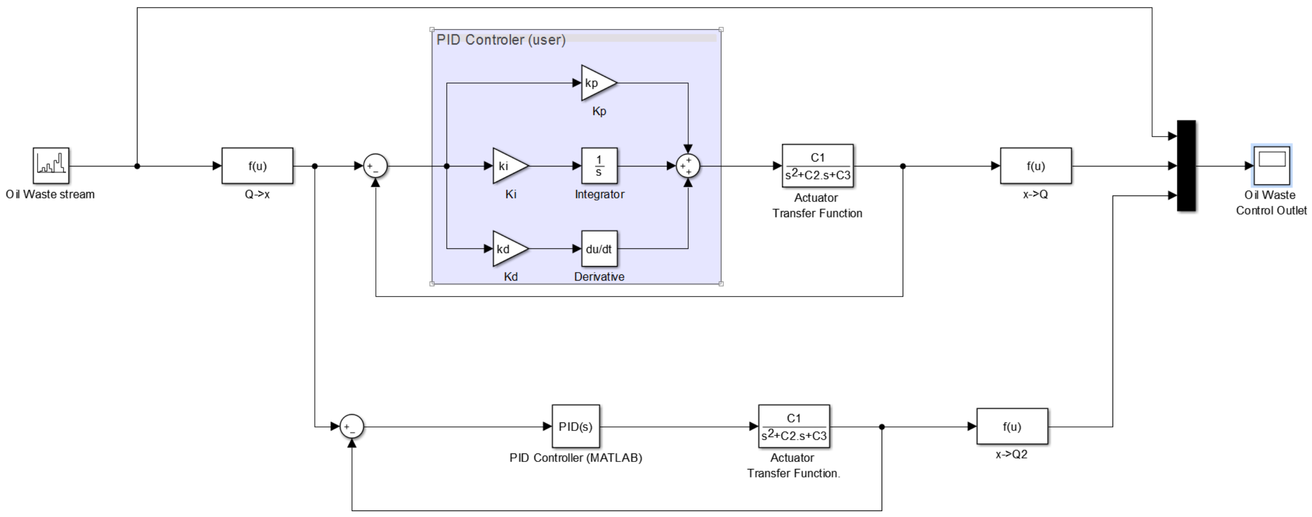

Figure 6. Close-loop control with PID controler build by the user and PID controler prefixed by MATLAB

Table 1. Constant of the globe valve

Stem Diameter (Dv)	13.525 mm
Diaphragm Diameter (Dd)	84 mm
Port Diameter (Dp)	26.7 mm
Chamfer Angle of the plug (α)	10°
Stem Mass (Mv) AISI 1020	169.15 gr
Plug Stem (Mt) AISI 1020	87.83 gr
Port Height (Ht)	3 mm
Pressure at the valve inlet (P1)	12.5 Pa
Pressure at the valve outlet (P2)	8.259 Pa
flux of the valve coefficient (Cv)	100 mm^3/s
Damping coefficient (c)	20
Spring coefficient (kr)	100

The results are obtained through the assignment of $\xi = 0.99$ with the aim of overdamped response, with stablished time (ts) of 2 seconds, to calculate ω_n with the equation (8) and a tolerance band of 1% (Tb).

$$t_s = \frac{abs(\ln(T_b))}{\xi * \omega_n} \tag{8}$$

With the characteristic polynomial of (6) in function of the gains Kp, Ki, Kd, is equal with the coefficients obtained in (7) as is describe in the equation (9).

$$K_p = \frac{20 * \xi^2 * \omega_n^2 + \omega_n^2 - \dfrac{k_r}{m_v + m_t}}{\dfrac{A_d - A_v}{m_v + m_t}} = 5.287 \tag{9}$$

$$K_i = \frac{10 * \xi * \omega_n^3}{\dfrac{A_d - A_v}{m_v + m_t}} = 5.9297$$

$$K_d = \frac{12 * \xi * \omega_n - \dfrac{c}{m_v + m_t}}{\dfrac{A_d - A_v}{m_v + m_t}} = 1.3117$$

With those value, then, is applied a step input (R(s)) to the system, obtained the results as exposed at the Figure-7. In the results is possible appreciate the behavior of the waste oil flow desired at the stablished time estimated by the control engineer, even so, can notice that with the PID control built by the user could show response with peaks that exceed the reference and could damage the actuator structure of the valve, whilst with the control predefined by MATLAB, avoid those errors achieving a behavior of a response damping desired.

CONCLUSIONS

With the develop of this work, we want to contribute in the built of virtual environment approximate to the industry, with the aim of watch over the execution of the process in the plant and in addition to help with the introduction of adjust of dynamics models and control of lineal systems in real time, in the academic. In this case, has in account the globe valve with pneumatic control, which require analysis the actuator dynamic, in charge of the stem position control, and the valve body, whose work focuses in allow the fluid flow.

The set of the control and transfer function blocks in close-loop, suggested with the graphic programming of SIMULINK, allow look the possible variation of the behavior system that depend of the control to use. In this case, is used the PID controller built by the user and the predefined by

MATLAB, where the results show the behavior desired of the system cause the second, due the adjust that has inside the block with the constant calculated previously.

Finally, is suggested as future work, the develop of virtual environments to oriented the user to the analysis of industrial process, identifying the elements that conforms each process (electric, mechanic, pneumatic, hydraulic, among others) and the control process necessaries to obtain the proper operation of the plant, proposing the methodology of the control to reach the desired results in the manipulation of the variables in the industry (level, flow, temperature, pressure, among others).

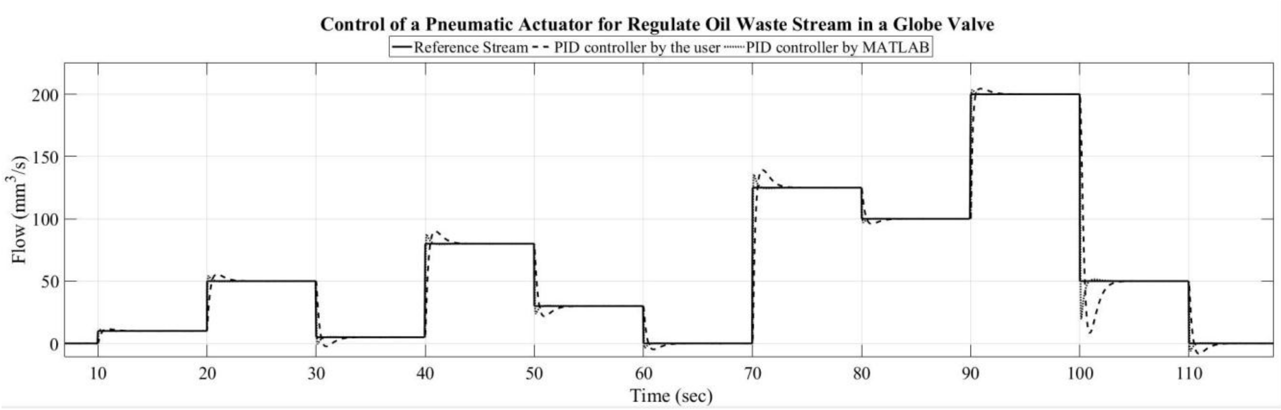

Figure 7. Flow response when using PID controller with the block designed by the user and with the block predefined by MATLAB

ACKNOWLEDGMENT

The authors would like to offer their special gratitude to the Research Vice-chancellorship of Nueva Granada Military University for financing the research project INV-ING-2370 titled: " Fase 2 de Laboratorio Virtual para el Control de Subprocesos en Refinación del Petróleo mediante la implementación de una arquitectura de control hibrido (Análogo-Eventos Discretos)", 2017

REFERENCES

[1] P. E. Carreño Hernández and J. Oswaldo Lozano, 2014. Ambientes virtuales de aprendizaje 3d. Congreso Iberoamericano de ciencia, tecnología, innovación y educación, November, 12 - 14, Argentina, pp: 1–15.

[2] C. A. Fredes, J. P. Hernández, and D. A. Díaz. 2012. Potencial y Problemas de la Simulación en Ambientes Virtuales para el Aprendizaje. Formación Universitaria. 5(1): 45–56.

[3] C. D. Q. Guerrero, E. L. S. Ballen, and W. J. S. Manrique. 2008. Diseño de un prototipo de sistema de realidad virtual inmersivo simplificado. Ciencia e Ingeniería Neogranadina. 18(1): 35–50.

[4] C. D. Yaguana Padilla. 2016. Estudio comunicacional del sistema de realidad virtual Kinect aplicado a videojuegos. Revista internacional de tecnología, ciencia y sociedad. 5(1): 121–133.

[5] V. Gatica Rojas, E. Elgueta Cancino, C. Vidal Silva, M. Cantin López, and J. Fuentealba Arcos. 2010. Impacto del Entrenamiento del Balance a través de Realidad Virtual en una Población de Adultos Mayores. International Journal of Morphology. 28(1): 303–308.

[6] C. López-Soler, M. Castro, M. Alcántara, and C. Botella. 2011. Sistema de realidad virtual EMMA-Infancia en el tratamiento psicológico de un menor con estrés postraumático. Revista de Psicopatología y Psicología Clínica. 16(3): 189–206.

[7] M. G. Mora. 2013. APLICACIÓN DE REALIDAD VIRTUAL EN LA REHABILITACIÓN COGNITIVA. Revista Vínculos. 10(1): 130–135.

[8] A. Bustos Sánchez and C. Coll Salvador. 2010. Los entornos virtuales como espacios de enseñanza y aprendizaje. Una perspectiva psicoeducativa para su caracterización y análisis. Revista Mexicana de Investigación Educativa. 15(44): 163–184.

[9] J. D. E. G. Velosa and E. C. Nieto. 2014. TAXONOMÍA DE LABORATORIOS Y ESTRATEGIAS E-LEARNING PARA LA FORMACIÓN EN MATERIALES Y PROCESOS DE MANUFACTURA. Revista Colombia de Materiales. (5): 114–122.

[10] A. L. G. Aspera and G. C. Hernández. 2011. La realidad virtual inmersiva en ambientes inteligentes de aprendizaje. Un caso en la educación superior. Revista de comunicación y tecnologías emergentes. 9(2): 122–137.

[11] J. A. F. Cruz, P. C. Gallardo, and E. A. Villarreal. 2014. La Realidad Virtual una Tecnología Innovadora

Aplicable al Proceso de Enseñanza de los Estudiantes de Ingeniería. Apertura. Revista de innovación educativa. 6(2): 86–99.

[12] L. Ramirez Ramirez, R. Castillo Mexicano, S. Goytia Acevedo, and R. Cruz Guerrero. 2014. DESARROLLO DE UNA ESTRUCTURA PARA LA ELABORACIÓN DE SIMULACIONES EN REALIDAD VIRTUAL, PARA LA ENSEÑANZA DEL MANEJO DE EQUIPO DE LABORATORIO. Academia Journal. 6(5): 3899 – 4041.

[13] J. de P. Carracedo and C. L. Martinez Mendez. 2012. Realidad Aumentada: Una Alternativa Metodológica en la Educación Primaria Nicaragüense. IEEE - RITA. 7(2): 102 – 108.

[14] O. Rangel and C. Enrique. 2011. Augmented reality in medicine. Revista Colombiana de Cardiología, 18(1): 4–7

[15] J. Gordo Ara. 2016. Video interactivo en realidad virtual inmersiva.

[16] L. Rischmoller, L. F. Alarcón, M. Fischer, and R. Fox. 2011. IMPACT OF COMPUTER ADVANCED VISUALIZATION TOOLS IN AEC INDUSTRY. Revista ingenieria de construccion. 17(2): 64–73.

[17] A. J. Fernandez Alvarez. 2010. DE LAS ARQUITECTURAS VIRTUALES A LA REALIDAD AUMENTADA: UN NUEVO PARADIGMA DE VISUALIZACIÓN ARQUITECTÓNICA. X Congreso Internacional Expresión Gráfica aplicada a la Edificación, December, 2-4, España, pp: 111 – 120.

[18] T. Barrientos-Gutiérrez, I. Barrientos-Gutiérrez, L. M. Reynales-Shigematsu, J. F. Thrasher, and E. Lazcano-Ponce. 2012. Aiming for the adolescent market: internet and video games, the new strategies of the tobacco industry. Salud Pública de México. 54(3): 303–314.

[19] M. C. Cuervo, J. G. Q. Salamanca, and A. C. A. Aldana. 2011. Ambiente interactivo para visualizar sitios turísticos, mediante la realidad aumentada implementando LAYAR. Ciencia e Ingeniería Neogranadina. 21(2): 91–105.

[20] A. M. A. García-Prieto and R. G. Sánchez. 2015. Análisis de la aplicación de la realidad aumentada en el sector turístico: una propuesta de mejora. GRAN TOUR, Revista de investigaciones turisticas. (10).

[21] O. M. Bianchi, E. Sosa, and A. J. M. Repetto. 2012. Real-Virtual World Interaction for training simulations WInter training. XIV Workshop de Investigadores en Ciencias de la Computación. Aphril, 26 -27, Mexico, pp: 673 - 677.

[22] M. Madueño Ortega. 2013. Control teleoperado del robot RV-M1 mediante dispositivo móvil y Realidad Aumentada.

[23] E. de la Fuente López and R. Mazaeda Echevarría. 2016. Industria 4.0.

[24] C. A. Cáceres and D. Amaya. 2016. Development and interaction of a virtual laboratory assisted and controlled by PLC. Entre Ciencia E Ingeniería. 10(19): 9–15.