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Autonomous Control Technique for an Air Hockey Table

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This article presents the construction of an air hockey table for testing control techniques used in robotic systems, the table consists of a two degrees of freedom robotic opponent; computer vision techniques are implemented using erosion and dilatation methodologies as part of mathematical morphology and the Pinhole camera model for detection and positioning of the robotic opponent. Each feature of the structure and construction of the pieces that constitute the mechanical system is detailed as well as the composition of the electronic system. The architecture of the table includes high-performance low-cost materials for this reason optimization design techniques and ergonomic designs are considered. Finally, the robotic opponent is tested with different autonomous control techniques i.e. a trajectory tracking control. The results show the efficiency of the construction of the air hockey table oriented to autonomous control methods.

Keywords: Air Hockey, Pinhole Camera Model, Construction, Autonomous Control Technique, Artificial Vision

1. INTRODUCTION

The development and release of new prototypes has now allowed robotics to advance by leaps and bounds achieving more robust and optimal new robotic systems which are also reliable and meet high performance requirements [1]. Different models and techniques of the new era of robotics have penetrated industry as well as home. Regarding industry, mobile and humanoid manipulators are responsible for performing multiple tasks in hostile and undefined spaces safeguarding the integrity of workers [2] [3] [4]. Similarly, robotics is now available in homes allowing the development of health systems, prototypes able to perform household chores and entertainment systems [5] [6] [7].

These days, there are multiple types of entertainment systems based on features and robotic components that in most cases allow total immersion of the user in a game. The development of entertainment platforms is spread in different areas such as the development of virtual environments such as driving simulations, humanoids performing as reprogrammable systems able to generate different postures and tasks, bipedal robots and insect simulators games. Similarly, the development of physical gaming platforms with robotic opponents that replace humans have taken root in entertainment robotics. Thus there are new techniques of data processing based on techniques of data processing based on artificial vision [8] [9] [10] [11] [12].

Table tennis, air hockey and chess are among the main table games whose construction of their gaming system with robot-assisted computer components based on image processing, modern control methods and robotic opponents within their platforms [13] [15]. Air hockey is a table game consisting of a flat air table and a puck. The game involves two opponents trying to insert the puck into the goal; the winner is the first player to accumulate more goals in the opposite goal, with a previously accorded numerical base [16].

This table game has experienced great changes in its constitution. The main change to emphasize is the inclusion of robotic opponents which allows greater autonomy when playing [14]. The design of this game with robotic elements agrees with ergonomic rules so that its design and architecture fits in with physical, psychological and physiological attributes of users. Therefore, these construction rules together with new modern control techniques based on artificial vision, robotic controllers with algorithms of optimization and prediction of movements form a robust and efficient entertainment system that fulfills to the required response objectives. [14][17][18].

Designs of air hockey tables are diverse; their assembly complexity depends directly on the complexity of their

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structure. In [19] a totally virtual air hockey game is created which can interact with more users within a network. However, the importance lies in the design of physical prototypes in order to provide the user with a real environment based on real parameters such as forces feedback and solid states of the real physical environment. The implementation of a physical air hockey table, essentially, allows the verification of fast tracking, decision motion, prediction algorithms and control systems with varied architectures for self-calibration and velocity and movement estimation [16] [18] [20]. That is to say, it is not just about the construction of a game or entertainment system, but it is based on the structuring with complete autonomous control systems with logical bases of control algorithms.

2. PROBLEM FORMULATION

Video game platforms and entertainment environments demand lower cost systems for the user. Although, currently there are multiple consoles and prototypes of games with diverse characteristics, they are not affordable for developers or researchers. For this reason, the target of new trends and applications is widely extended to different areas of communication and control technologies in order to optimize costs and system resources. Artificial vision composed by new algorithms and control patterns has directly penetrated in the development of entertainment systems.

Nevertheless, there are several game platforms that have not been perfected for the ergonomic use of the user. Such is the case of the table game Air hockey which needs two people to be played in an entertaining, friendly and autonomous way. If there is only one opponent the game cannot be played. This is the reason for the need of the development of new automatic control platforms that allow the playability of a table game just having a single player by implementing robotic high performance robotic opponents, position, ergonomics which can directly obviate the other opponent so that the user can interact with the game without restrictions.

3. DESIGN AND CONSTRUCTION

A. Structure

The constitution of the table is directly related to the interaction between the mechanical components of control and the electronic data transmission and reception systems The construction of the table is formed of two structures that interact to achieve the movements of the robotic control in function of the positions obtained by the techniques of artificial vision. Fig. 1 details an interaction diagram between the elements that constitute the table.

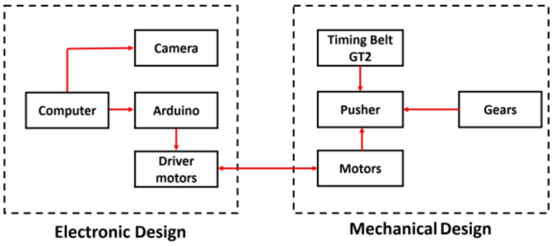


Fig. 1: Electronics and Mechanical scheme of the table.

The electronic systems act as a function of the data obtained by the camera, the desired position is analyzed directly by the algorithm of artificial vision developed in the computer; then control actions are sent to the Arduino platform which is interconnected to the motor drivers that deliver the necessary power to the actuator. The mechanical system consists of gears and 3D printed components in order to lower costs and optimize mechanical resources. See Fig. 5; the conveyor is one of the main motion elements; it allows the work area of the actuator to be set up in two dimensional axes X-Y.

The construction of the table consists of several fundamental aspects which must be analyzed and carried out in a precise and systematic way. The first essential step for the development of the complete system of actuators and controllers is the general design which sketches each one of the components to be used in the construction of the table. Fig. 2 highlights the three-dimensional design of the air hockey table to be implemented.

Fig. 2: Design and Composition of the Air Hockey Table

The design and construction of the table is based on features and rules of air hockey. It also takes into account aspects of ergonomics in entertainment systems. Its electronic and mechanical structure composition emphasizes a robust and high precision system thanks to the implementation of advanced artificial vision advanced algorithms.

B. Mechanical Design.

The mechanical design is based on different rules of physical and physiological ergonomics in order to provide the user with greater comfort when interacting with the table. The first aspect of construction is the structuring of a frame which supports the table structure and the composition of the robotic opponent. The table frame is constructed of wood, which is a ductile element capable of absorbing and eliminating vibrations from mechanical sources; Fig. 3 details the base of the table frame.

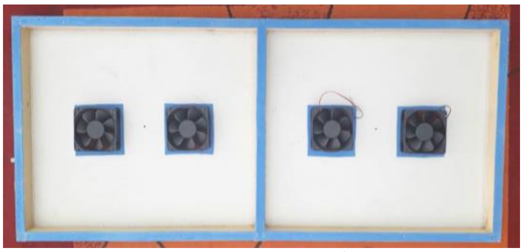


Fig. 3: Air hockey Table frame.

The frame is 140x60 [cm] which makes the table a highly immersive prototype with a high degree of usability; the base of the table on which the puck moves is completely smooth. The vertical impulse of the puck is performed by air which is generated by fans located inside the table frame. The hollow air cavities are distributed along the smooth surface so that the disk floats at a constant millimeter height throughout the surface; the minimum contact exerted on the disc allows its displacement in function of the impact force exerted. Finally, at the sides of the table battens are placed as a containment system and puck pivot. Fig. 4 shows the smooth structure of the table and the hollow air cavities for the puck to float.

The mechanical transmission system is constituted by gears and techniques of conveying movement to the motors. The present work counts with the design and impression of 3D pieces for structuring the system of movement and the transmission of forces; the design and the printing of these pieces allow the movement system to have the maximum efficiency corresponding to the transmission ratios, torque, energy consumption, speed of response, ergonomics and compatibility with the surfaces of the table frame. Fig. 5 represents some of the pieces designed and printed in 3D in order to obtain the characteristics descripted above.

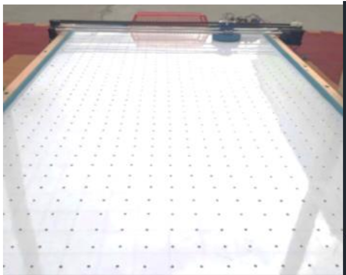


Fig. 4: Frame, smooth surface and hollow air cavities of the Air Hockey

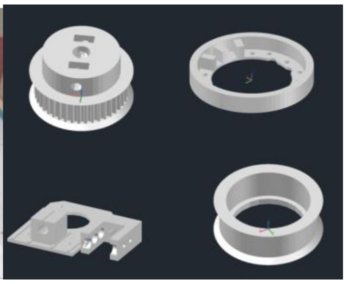


Fig. 5: 3D printed parts for conveying and motion control

For displacing of the opponent's control, the table is composed of 3 NEMA17 48N-cm motors which are responsible for the movement of the control on the X-Y axes. The implementation of motors and data transmission components is illustrated below.

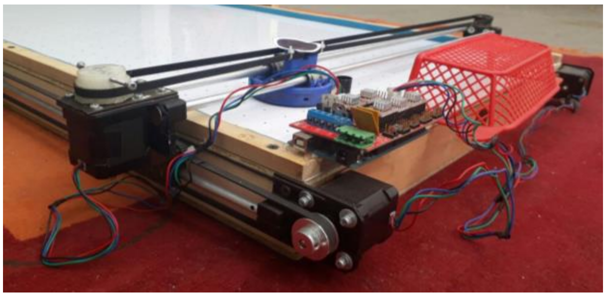


Fig. 6: Opponent´s Mechanical Motion System .

C. *Electronic Design*

It consists of different components that allow data acquisition, communication with the motors and the control system. The camera is the main device of data acquisition by capturing successive images which will be previously analyzed by advanced algorithms of artificial vision:

A diagram of the air hockey table electronic system is illustrated in Fig 7. A Logitech HD Pro Webcam C920 is in charge of image acquisition It captures successive images of the puck position on the table, this data is collected by a computer, where the artificial vision algorithms are performed. This data processing is directly linked to the speed of the processor of the computer. The computer used for this table meets the following characteristics: Intel i7, 16 GB in RAM and Windows operating system running MATLAB software which is in charge of the artificial vision algorithm and logic control for moving the motors.

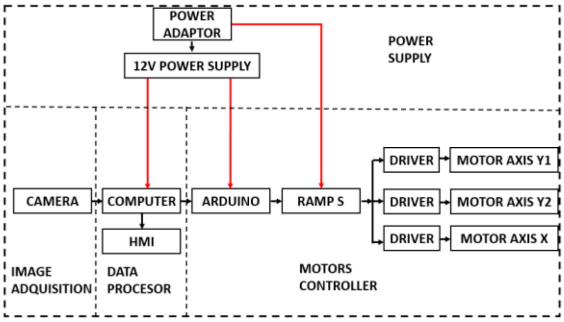


Fig. 7: Scheme of the Electronic System

An Arduino Mega Board is used for controlling the motors, sending data through a serial port with 3 information signals for each one of the motors. The signals represent speed direction of rotation and polarization of the motors. Besides the Arduino Mega Board a RepRap Arduino Mega Pololu Shield (RAMPS) is used for handling and supplying current and protecting the NEMA17 48N-cm motors. Finally, each RAMPS is wired to the motor driver.

Regarding motors which work as the system actuators giving mobility to the robotic controls from the control signals descripted above. They are located on the frame of the table and place the control in a specific position for kicking the puck. Two motors are intended for displacement in the Y axis and one motor for displacement in the X axis. The region where the control moves to kick the puck is known as the working area. The motors and fans are connected to 12 V /2A power supply. The system includes an adaptation control unbalanced current and energy compensation when the motors are driven by the RAMPS.

D. *Visión*

In order to control the autonomous robot with the data provided by the artificial vision system, it is necessary to understand the geometry of imaging process. Each camera has a lens that creates a 2D projection of the scene in the image plane where the sensor is located. This projection causes loss of direct depth perception so that each point in the plane of the image corresponds to a beam in 3D space. Therefore, some additional information is needed to determine the 3D coordinates corresponding to an image plane point. This data is provided by multiple cameras, multiple views from a single camera, or by knowing the geometric relationship of several feature points of the target. The camera model used in this document is the Pinhole Camera Model. It implies a simplified model for an ideal vision camera without distortion ot optical aberrations, see Fig. 8 [21].

The projection model of the camera is based on Pinhole, Camera Model assuming that the aperture of the camera is a purely refractive lens. Obtaining mathematical equations describing a three-dimensional point ${}^{c}\mathbf{p}_\mathbf{i} = \left[{}^{c}\mathbf{x}_\mathbf{i}, {}^{c}\mathbf{y}_\mathbf{i}, {}^{c}\mathbf{z}_\mathbf{i}\right]^\mathbf{T}$ in a two-dimensional plane is based on the analysis of Fig. 8. In this way, a point ${}^{c}\mathbf{p}_\mathbf{i}$ ttaken from the real object is placed on the image plane (u,v) and described as $\boldsymbol{\xi}_\mathbf{i}$.

To obtain the model, the analysis is performed for each two-dimensional axis as shown in Fig. 9, observing that the focal length is the distance from the lens to the camera sensor and considered as a constant value.

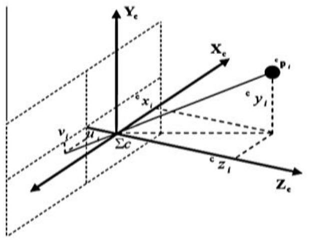


Fig. 8: Pinhole Camera Model Illustration

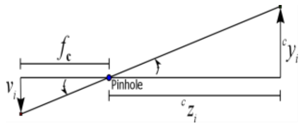


Fig. 9: Formulas Analysis based on the Pinhole Camera Model

The value on the v axis of the image plane of each of the pixels can be found using geometric similarity. So that, the relationship created by sharing the same angle allows determining that

$$u_i = -\frac{f_c({}^c x_i)}{{}^c z_i}, v_i = -\frac{f_c({}^c y_i)}{{}^c z_i} \tag{1}$$

To find the velocity on the axes of the image plane, the derivative of (1) is calculated. Since the camera is in a static position the axis Z is considered constant.

$$\dot{u}_i(t) = -\frac{f_c({}^c \dot{x}_i(t))}{{}^c z_i}, \dot{v}_i(t) = -\frac{f_c({}^c \dot{y}_i(t))}{{}^c z_i} \tag{2}$$

Clearing interest variables ${}^c \dot{x}_i$ y ${}^c \dot{y}_i$ de (2), the matrix representation shown in (3) is determined to find the real speed of the object on the general reference plane.

$${}^c\dot{\mathbf{p}}_\mathbf{i}(t) = \begin{bmatrix} {}^c \dot{x}_i(t) \\ {}^c \dot{y}_i(t) \end{bmatrix} = -\frac{{}^c z_i}{f_c} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{u}_i(t) \\ \dot{v}_i(t) \end{bmatrix} \tag{3}$$

More abstractly, the representation of a three-dimensional point (in this case a two-dimensional representation because of the invariance of the Z-axis) in a two-dimensional image plane proposes the following equality:

$${}^c\dot{\mathbf{p}}_\mathbf{i}(t) = \mathbf{M}\dot{\boldsymbol{\xi}}(t) \tag{4}$$

where

$$\mathbf{M} = -\frac{{}^c z_i}{f_c}\mathbf{I_{2x2}} \tag{5}$$

4. TRAJECTORY CONTROL

To validate the system, a control algorithm based on trajectory tracking is implemented, the desired path is entered into the processor, and then it is drawn onto the working plane. Error calculation is made through image processing.

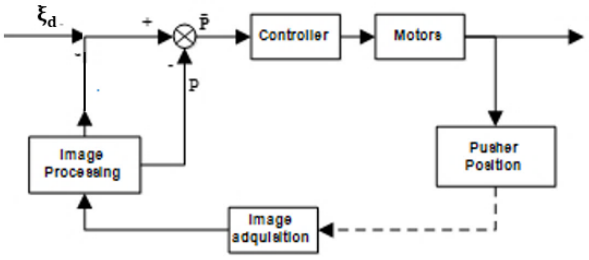


Fig. 10: Control System Diagram.

The controller corrects the position of the robotic opponent, the location of the center of the kicker and the center of the puck are used as input information for the controller to generate control actions that change the position of the robotic opponent considering the work area where it scrolls up and down. Fig. 10 shows the block diagram of the control system.

Trajectory tracking considers both axes u and v to generate a response based on (3):

$${}^c\dot{\mathbf{p}}_\mathbf{i}(t) = \boldsymbol{\upsilon}(t) = \begin{bmatrix} {}^c \dot{x}_i(t) \\ {}^c \dot{y}_i(t) \end{bmatrix}$$

$$\boldsymbol{\upsilon}(t) = \mathbf{M}\dot{\boldsymbol{\xi}}(t) \tag{6}$$

With this control, both position errors $\tilde{u}$ y $\tilde{v}$ known as $\tilde{\boldsymbol{\xi}}$ are considered to obtain a control law determined by:

$$\boldsymbol{\upsilon}(t) = \mathbf{M}(\mathbf{K_1 tanh}(\mathbf{K_2}\tilde{\boldsymbol{\xi}}(t)) + \dot{\boldsymbol{\xi}}_\mathbf{d}(t)) \tag{7}$$

Where error is presented as $\dot{\tilde{\boldsymbol{\xi}}}(t) = \dot{\boldsymbol{\xi}}_\mathbf{d}(t) - \dot{\boldsymbol{\xi}}(t)$, $\dot{\boldsymbol{\xi}}_\mathbf{d}(t)$ is the derivative of thr desired path and sets up the following conditions $\mathbf{K_1} > 0$ and $\mathbf{K_2} > 0$ considered as positive defined matrixes so that the system is stable.

5. RESULTS AND ANALYSIS:

The performance evaluation of the air hockey table is made from two experiments described in this section. The first experiment verifies the movement of the motors manually, presenting graphs of errors and the velocities applied to the actuators. The second experiment evaluates the proposed control system through trajectory tracking. It presents the graphs of error and the velocities applied to the actuators.

Fig. 11: Graphical User Interface for interacting with the user

Experiment I. This experiment concentrates on checking the movement of the actuators manually; at a desired speed and position for this a Graphical User Interface (GUI) is created in MATLAB. It can interact with the user as presented in Fig.11. A desired velocity is given in [m/s], it also needs a X and Y position within the work area of the robot Fig.12.

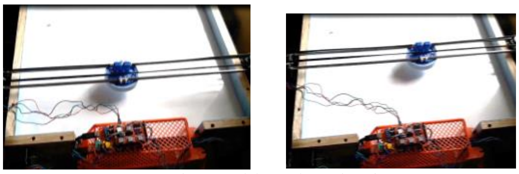
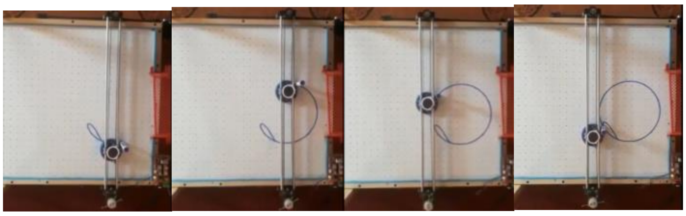


Fig. 12: Robot position given by the user.

Experiment II. This experiment focuses on evaluating the performance of the controller mentioned in Section 4, where the trajectory tracking is implemented. The test includes a graphical representation of the trajectory followed by the autonomous robot to check the tracking retention, therefore two paths are designated. The first is the representation of a circular function represented in Fig 14. The second path is s heart curve function illustrated in Fig. 17; the trajectories followed by the autonomous robot of the above-mentioned curve functions are shown in Fig. 13 and Fig. 16 respectively denoting the trajectory track satisfactorily. An analysis of error of each curve function performed by the autonomous robot is made. The circular function is represented in Fig. 15. It corresponds to the error in the plane u v of the circular path. Similarly in Fig. 18 the errors are represented in the u v plane for the heart curve function path.



Time 8 [seconds] Time 16 [seconds] Time 24 [seconds] Time 30 [seconds]

Fig. 13: Controller response for a circular path

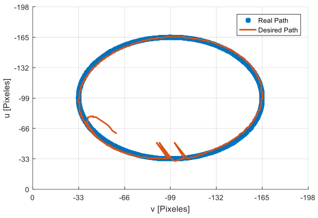


Fig. 14: Real Path vs Desired Path

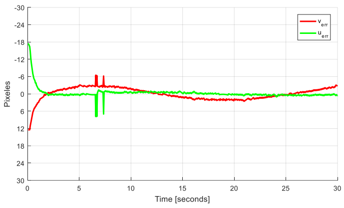
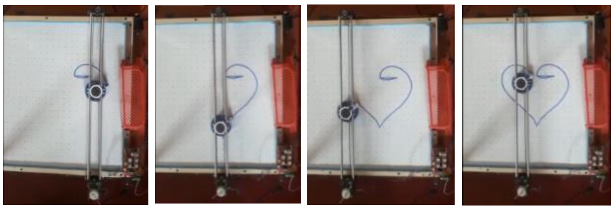


Fig. 15: Errors on the u and v plane



Time 8 [seconds] Time 16 [seconds] c) Time 24 [seconds] d) Time 30 [s]

Fig. 16: Controller response for a heart curve path.

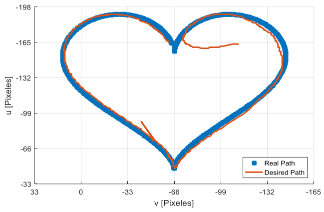


Fig. 17: Real Path vs. Desired Path

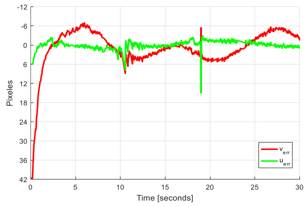


Fig. 18: Error son the u and v plane

6. CONCLUSIONS

This article presents the construction of an ergonomic and low-cost air hockey table, with an autonomous two-degrees-of -freedom robotic opponent. It is based on the Pinhole Camera Model to obtain the kinematic model of the camera. It determines the speed of the targets and trajectory tracking is implemented to verify the efficiency of the system.

REFERENCES

[1] N. Ackovska and V. Kirandziska, "The importance of hands-on experiences in robotics courses," IEEE EUROCON 2017 -17th International Conference on Smart Technologies, Ohrid, Macedonia, 2017, pp. 56-61.

[2] Andaluz V.H., Ortiz J.S., Sanchéz J.S. (2015) Bilateral Control of a Robotic Arm Through Brain Signals. In: De Paolis L., Mongelli A. (eds) Augmented and Virtual Reality. AVR 2015. Lecture Notes in Computer Science, vol 9254. Springer, Cham.

[3] H. Cheng, H. Chen and Y. Liu, "Object handling using Autonomous Industrial Mobile Manipulator," 2013 IEEE International Conference on Cyber Technology in Automation, Control and Intelligent Systems, Nanjing, 2013, pp. 36-41.

[4] J. Guérin, O. Gibaru, E. Nyiri and S. Thiery, "Learning local trajectories for high precision robotic tasks: Application to KUKA LBR iiwa Cartesian positioning," IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society, Florence, 2016, pp. 5316-5321

[5] D. Popescu, M. Ivanescu, R. Popescu, L. C. Popescu, A. Petrisor and A. M. Bumbea, "Post-stroke assistive rehabilitation robotic gloves," 2016 International Conference and Exposition on Electrical and Power Engineering (EPE), Iasi, 2016, pp. 360-365.

[6] A. Kanemura et al., "A waypoint-based framework in brain-controlled smart home environments: Brain interfaces, domotics, and robotics integration," 2013 IEEE/RSJ International Conference on Intelligent Robots and Systems, Tokyo, 2013, pp. 865-870.

[7] Hyun Wook Kim and S. Jung, "Design and analysis of a robotic vehicle for entertainment using balancing mechanism," 2011 8th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), Incheon, 2011, pp. 855-857.

[8] Andaluz, Víctor & Gallardo, Cristian & Santana, Jaime & Villacres, Johana & Toasa, Renato & Vargas, Javier & Reyes, Gabriel & Naranjo, Tannya & Sotelo, Andrea. (2012). Bilateral Virtual Control Human-Machine with Kinect Sensor. 101-104. 10.1109/Andescon.2012.32.

[9] I. W. Jeong, Y. H. Seo and H. S. Yang, "Effective humanoid motion generation based on programming-by-demonstration method for entertainment robotics," 2010 16th International Conference on Virtual Systems and Multimedia, Seoul, 2010, pp. 289-292.

[10] H. Hirukawa, F. Kanehiro, K. Kaneko, S. Kajita and M. Morisawa, "Field and service appkications - Dinosaur robotics for entertainment applications - Design, Configurations, Controt, and Exhibition at the World Exposition," in IEEE Robotics & Automation Magazine, vol. 14, no. 3, pp. 43-51, Sept. 2007.

[11] M. Fujita, "Digital creatures for future entertainment robotics," Proceedings 2000 ICRA. Millennium Conference. IEEE International Conference on Robotics and Automation. Symposia Proceedings (Cat. No.00CH37065), San Francisco, CA, 2000, pp. 801-806 vol.1.

[12] K. A. Zubair, S. Singha, S. Alam and Kazi Tanvir Ahmmed, "Humanlike robotic vision system using artificial neural network," 2015 2nd International Conference on Electrical Information and Communication Technologies (EICT), Khulna, 2015, pp. 13-18.

[13] A. Nakashima, K. Takayanagi and Y. Hayakawa, "A learning method for returning ball in robotic table tennis," 2014 International Conference on Multisensor Fusion and Information Integration for Intelligent Systems (MFI), Beijing, 2014, pp. 1-6.

[14] C. Marra, D. Cattenazzi, A. Masinovic and J. Zheng, "Design and implementation of a vision-based robotic air hockey table," Proceedings of 2014 International Conference on Modelling, Identification & Control, Melbourne, VIC, 2014, pp. 105-110.

[15] M. Atas, Y. Dogan and S. Atas, "Chess playing robotic arm," 2014 22nd Signal Processing and Communications Applications Conference (SIU), Trabzon, 2014, pp. 1171-1174.

[16] Y. C. Li and S. Y. Huang, "Fast-moving object tracking in air hockey," 2017 IEEE International Conference on Mechatronics and Automation (ICMA), Takamatsu, Japan, 2017, pp. 1693-1697.

[17] X. Zhang, L. Xue, S. Li and F. J. Kim, "Digital human modeling for ergonomic evaluation of patient table height," IEEE Int. Conference on Robotics and Biomimetics (ROBIO), Shenzhen, 2013, pp. 1480-1485

[18] Víctor Andaluz, Flavio Roberti, Juan Marcos Toibero, Ricardo Carelli, Adaptive unified motion control of mobile manipulators, Control Engineering Practice, Volume 20, Issue 12, 2012, Pages 1337-1352.

[19] H. Matsuura, N. Abe, K. Tanaka and H. Taki, "Constructing virtual air hockey game through the network," 20th International Conference on Advanced Information Networking and Applications - Volume 1 (AINA'06), Vienna, 2006, pp. 5 pp.-.

[20] S. Rezvankhah, A. A. Bagherzadeh, H. Moradi and B. N. Araabi, "A real-time velocity estimation using motion blur in air hockey," 2012 IEEE International Conference on Robotics and Biomimetics (ROBIO), Guangzhou, 2012, pp. 1767-1772.

[21] Víctor Andaluz, Ricardo Carelli, Lucio Salinas, Juan Marcos Toibero, Flavio Roberti, Visual control with adaptive dynamical compensation for 3D target tracking by mobile manipulators, Mechatronics, Volume 22, Issue 4, 2012, Pages 491-502, ISSN 0957-4158.