

# Educational Robotic Platform of Low Cost for Brain and Servovisual Control Practice

EDWARD VEGA, CESAR PEÑA, ALDO PARDO  
Department of Mechanics, Mechatronics and Industrial Engineering  
University of Pamplona  
Citadel University, Km 1 via Bucaramanga, Pamplona  
COLOMBIA

edward.vega@live.com, cesarapc@unipamplona.edu.co, apardo13@unipamplona.edu.co

**Abstract:** - This paper proposes an educational robotic platform. It allows developing several practices in: automation, robot kinematic control, servo-vision using the camera IP or kinect device, neuro-signals processing with the EPOC emotive device, brain control, teleoperation and others. This platform is characterized by the movement simulation of the robot, while it detects interference between the elements. The paper presents the robot characteristics, some economical analysis and control structure using kinect and EPOC emotive devices.

**Key-Words:** - Educations, robotics, brain, vision, control.

## 1 Introduction

One of the main problems of South-American universities is the low budget for laboratories. For example, the cost of robotics laboratories is so high and that is why, these universities must replace real practices by simulations with specialized software. The University of Pamplona has a robotics laboratory with a reduced number of devices and equipment. In order to improve the education quality in this subject, the research group of Automatics and Control is designing several platforms. It has projects in parallel and serial robotics workstations, vision platform, automation systems and other.

This paper proposes an educational robotic platform of low cost. The goal of this platform is to develop several laboratory practices in vision and brain control in order to strengthen robot kinematics knowledge.

The platform proposed uses a Kinetic device of Microsoft. This device was produced for videogame consoles. The goal is start using the device with games and subsequently to program it. This device gives us the opportunity to use only students' bodies as a control [5] to move remotely the robot.

In the last years this device has allowed the development of several applications in a lot of fields as: medicine [3], [8], [1], aerospace industry [11], haptics [2], aeronautics [9], metrology [7], robotics [6], [4] and other.

Another technique to motivate students is by using recent technology. For this reason the platform proposed use a Brain Computer Interfaces (BCI).

The BCI selected is the EPOC Emotive system, which is neuro-signals capture device of high resolution [10]. This low cost headset allows interpreting some user thoughts to generate the commands to control the robot.

This kind of devices were created based on electroencephalography (EEG). This technology is based on neurophysiological examination using bioelectrical activity logs of the brain. Nowadays, a lot of applications are being developed, due to the high potential that they provide, some examples are: [12], [10].

The general idea of the platform proposed is to capture the users' movements or thoughts in order to be processed and generate the control signals. These signals are sent by a net (LAN or Internet) using UDP (User Datagram Protocol). A robot controller (implemented on Arduino device) receives the signals and it generates the path planning to achieve the desired references.

This paper is organized as follows. The section 2 presents the platform characteristics, the sections 3 and 4 show the servo-visual and brain control. Finally, the section 5 displays the results.

## 2 Platform Characteristics

Two zones compose the platform. The first one has a graphical interface, the input device (kinect or BCI) and a computer where the controller of high level is programmed. The second zone has a robot of 5 degrees of freedom (DOF), a camera IP in order to feedback to the remote user and an Arduino device where a remote controller is implemented (low level).

### 2.1 Robot Characteristics

The robot must have a low cost, in order to be replicated. Likewise, building materials should be easy to obtain.

The robot arm was modeled using software of computer aided design (CAD). This model allows improving the robot structure and correct prior mistakes to build it.

Also it was verified the direct and inverse kinematic in order to simulate the robot movements. The main interferences of the link have been detected by the simulations and with them they can be reduced.

Once the robot final version was adopted, it proceeded to use the software Visual c++ to simulate the robot. These simulations use OpenGL libraries to verify graphically the robot movements. See Figure 1.

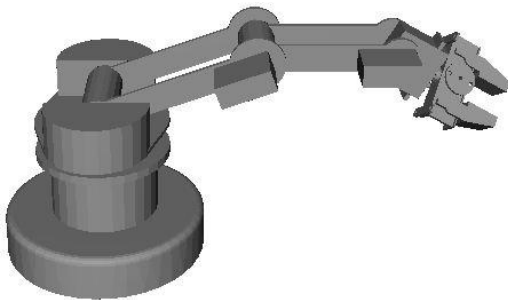


Fig.1. Robot Simulation using Open GL.

In order to select the robot motors, it proceeded to estimate the max torques that should supply every joint (see table 1). These torques are estimated following criteria such: critical positions, path-planning to develop and mechanical parameters. For the development of these calculations it was necessary to apply the robot dynamic model based on Lagrange-Euler method.

It should be taken into account that the robot components must be at low cost and easily achievable. For this reason it was decided to work with standard servomotors.

Joint	Max Torque(Kgf/cm)
1	4,620
2	8,137
3	5,397
4	4,729
5	2,583

Table 1. Joint Max Torques.

The table 2 shows the technical features of the selected servomotors.

SERVO	Tower Pro MG995	Tower Pro Standard	Futaba S3003	Futaba S3010
Weight (g)	55,0	38,0	37,2	41
Torque (kgf/cm)	8,5	5,8	3,2	6,5
Velocity (s/60°)	0,16	0,16	0,19	0,16
Voltage (V)	4,8-7,2	4,8-6,0	4,8-6	4,8-6
Temperature Range (°C)	0 – 55	0 – 55	0 – 55	0 – 55
Dead band width	7us	5us	5us	3us

Table 2. Servomotor Features

#### 2.1.1 Building

The anthropomorphic robot design was based on mathematic calculations and it was verified by simulation with software CAD in order to correct the mistakes. Subsequently, the mechanical design was implemented. The robot parameters were adjusted to obtain a very similar behavior between the simulations and the real experiments. The Fig. 2 shows the final robot.



Fig. 2. Anthropomorphic Robot of 5 GDL

#### 2.1.2 Control Board

In order to implement the communication system and the motors control an Arduino board was selected. This board allowed implementing a communication channel (Internet or LAN) with the computer using a universal datagram protocol

(UDP). It also allowed to generate the pulse width modulation signals to control every servomotor.

### 2.1.3 Economical Analysis

The robot was designed with low cost elements in order to be replicable. For example the principal link material is acrylic because it is cheaper than aluminum sheets and these do not require laser cutting. The motors are placed directly over the joints. This characteristic avoids using movement transmission systems like gearbox or pulleys reducing costs and complexity. The robot was also designed to be easily assembled. The final robot arm cost is near to 250 dollars.

## 2.2 Robot Kinematics

By the geometric method the angles  $q_1$ ,  $q_2$  and  $q_3$  were obtained. The Fig. 3 shows a top robot view, which allows obtaining the angle  $q_1$  from end effector coordinates ( $P_x$ ,  $P_y$ ). Likewise, the Fig. 4 shows a lateral view that allows calculating the equations corresponding to the angles  $q_2$  and  $q_3$ .

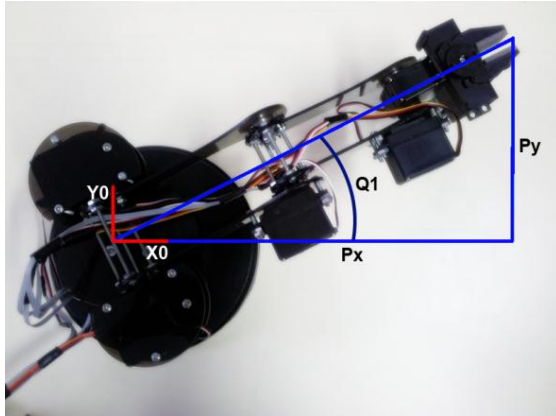


Fig. 3. Angle of the first joint (robot base) -  $q_1$

The following is the calculation of the first three degrees of freedom. The first joint angle can be obtained as:

$$q_1 = \text{atan2}(p_y, p_x) \quad (1)$$

$P_m$  is the robot wrist point, see (2). It is obtained using kinematic decoupling method in order to calculate the angles  $q_2$  and  $q_3$ .

$$P_m = P_5 - (L_4 + L_5) * Z_5 \quad (2)$$

Where:

$P_m$ : the wrist point.

$P_5$ : End effector coordinates - "xyz".

$L_1, L_4, L_5$ : Lengths of the robot links.

$Z_5$ : Component z of the coordinate system 5 (End effector system).

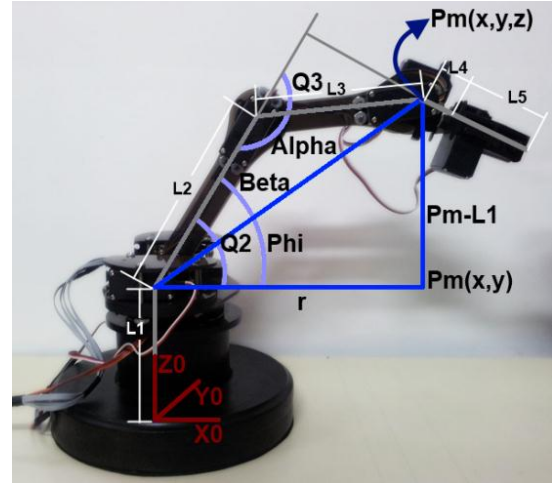


Fig. 4. Robot Left view

The equation 3 shows the projection of the point  $P_m$  over the plane 'xy'.

$$r = (P_m^2_x + P_m^2_y)^{1/2} \quad (3)$$

The length between the point  $P_m$  and the second joint ( $d$ ) can be calculate as:

$$d = (r^2 + (P_m_z - L_1)^2)^{1/2} \quad (4)$$

Using the cosine law over the triangle, it can calculate the angle  $\text{Alfa}$  from the equations 5, 6 y 7.

$$\cos(\text{alfa}) = \frac{d^2 - L_2^2 - L_3^2}{-2 * L_2 * L_3} \quad (5)$$

Therefore:

$$\sin(\text{alfa}) = \mp(1 - \cos(\text{alfa})^2)^{1/2} \quad (6)$$

$$\text{alfa} = \text{atan2}(\sin(\text{alfa}), \cos(\text{alfa})) \quad (7)$$

Then it can calculate the angle  $q_3$  as:

$$q_3 = 180 - \text{alfa} \quad (8)$$

The angle  $q_2$  (see 13) is obtained from the sum between  $\phi$  and  $\beta$ ; see (14-15).

$$q_2 = \phi + \beta \quad (9)$$

$$\phi = \text{atan2}((P_m_z - L_1), r) \quad (10)$$

$$\beta = \text{atan2}(L_3 * \sin(q_3), L_2 + (L_3 * \cos(q_3))) \quad (11)$$

With the parameter Gamma " $\gamma$ ",  $q_4$  is calculated as show in (12).

$$q_4 = q_2 - q_3 - \gamma \quad (12)$$

The angle  $q_5$  (see 13) can be calculated without any additional algorithm because it takes the same value of the angle Delta " $\delta$ ".

$$q_5 = \delta \quad (13)$$

### 3 Robot Control

To apply the inverse kinematic model by the geometric method, the robot user must define the end effector position and orientation. The results of this algorithm are the 5 joint parameters (angles). With the first 3 parameters the user defines the end effector position and with the last 2 parameters defines the orientation. In order to define these input parameters, the user can select between two controllers: servo-visual and brain control.

#### 3.1 Servo visual control using Kinect

The idea is use the kinetic device to capture the position of the user arm and calculate the robot references in order that the robot follows the user.

The coordinates that define the robot position into the workspace correspond to the user hands coordinates in space. The movements of the user right hand define the evolution in position of the robot. The position of the user left hand defines the robot end effector orientation (define the parameters:  $\gamma$  y  $\delta$ ).

The Fig. 5 shows the user skeleton view. The blue zone is the workspace. It performed an analogy between the robot and the user arm. For example the third joint correspond with elbow and the robot base with the user shoulder.

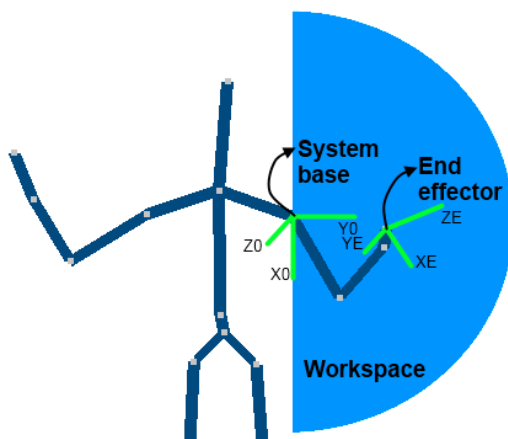


Fig. 5. User skeleton view.

The system has and graphical interface that shows the robot movements from the commands defined by the user body movements. This interface allows to the user learning the robot control safely. The Fig. 6 shows the main functions of the interface. It has the user skeleton view, the images from deep camera and the real or simulate position of the robot.

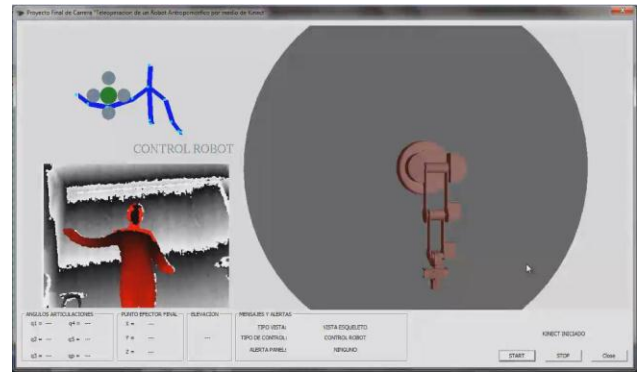


Fig. 6. Robot Graphical Interface

#### 3.2 Brain control

Nowadays the development of brain interfaces is a reality, both research and commercial fields. One relevant example is the interface developed by Emotiv company [10]. This interface (see Fig. 7) is a low cost neuroheadset, witch has 16 sensors to capture brain signals.



Fig. 7. EPOC Emotiv Interface

The Fig. 8 shows how the EPOC interface can capture the neuro-signals. With the processing of these signals, the user can define a lot of commands to control a robot. It can choose among 3 work modes: Expressive, Affective and Cognitive. With the expressive mode, the user can control the robot by facial expressions as: eye movements, smile, clench, blink, eyebrow wink and other. The affective mode is used to capture the mood user (Focus level, calm, excitement and others). This mode is rarely used, but could be applied for example to improve the robot autonomy level when the user is distracted. The last is the cognitive mode. In this case the user can control the robot thinking directly in a particular movement, for example: up, down, left, right, rotations and other movements.



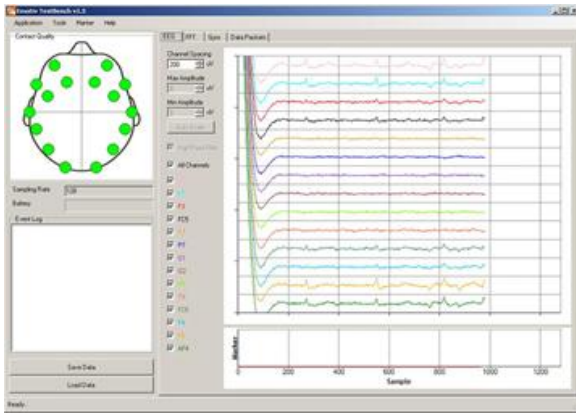


Fig. 8. Neuro-signals captured with EPOC Emotiv.

The general idea is obtain the robot references from the user brain. The user selects a mode and defines the robot movements. With these movements the algorithms calculate the path planning to be executed by the robot.

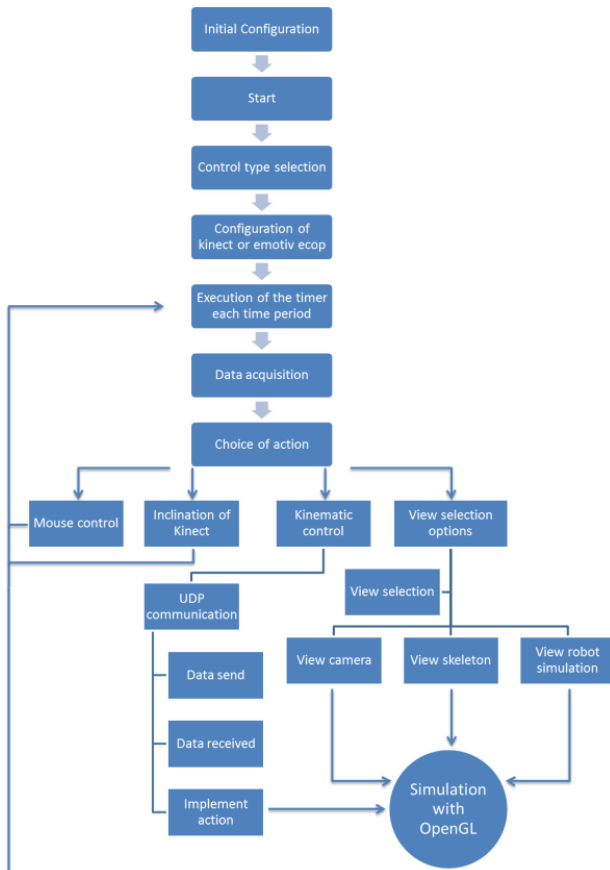


Fig. 9. Software flowchart

### 3.3 Software algorithms

The software was developed in Visual C++. The Fig. 9 shows the software flowchart. This includes the use of OpenGL libraries, the communications, kinematics algorithms and others.

To start the program, it initializes the socket in order to establish a communication between the robot and the computer. Also are loaded the initial configuration of the EPOC Emotiv device or Kinect device. Subsequently, it is active a timer. This timer develops the tasks according to execution mode and the device selected. Some tasks are: the command capture from the user, command execution, robot actions, display of robot simulations and several data like position and velocity.

Moreover, the user can change the simulation views and defines the orientation of a remotely camera, in order to visual feedback to realize the tasks.

## 5 Results

The main advantage of proposed platform is its low cost, the flexibility, the functionality, easy construction and replication. The table 3 shows the price of similar commercial robots. The final platform price is near to US\$ 250.

Commercial Robot	COST (US\$)
Robot ArmC-9895	471
Robot Arm S300123	606
Robot Arm S300128	789
Robot Arm AL5A	574

Table 3. Price of similar commercial robots.

With the platform was verified: the robot movements into the workspace, the capture of user movements by Kinect and the command defined by neuro-signals capture with EPOC device, the robot simulations, the visual feedback with the remote camera by Internet and teleoperation task as take and move objects.

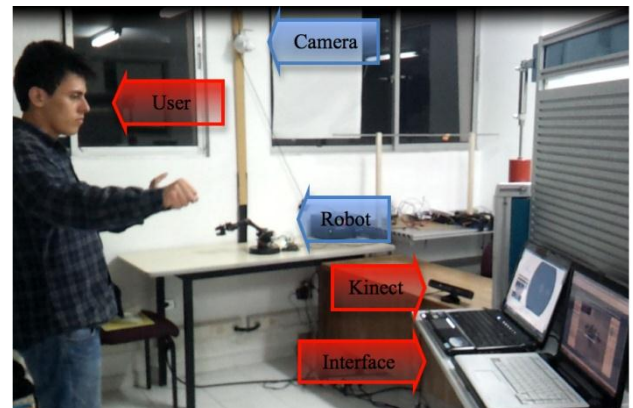


Fig. 10. Platform of the teleoperation system

The Fig. 10 shows a teleoperation system using the platform proposed. In this application the input device is the kinect device in order to capture the user movements. This figure presents the devices that compose the local zone (user, kinect, graphical interface, computer) and the remote zone (robot, camera IP). In this image appears two computers however only is necessary one. The use of two computers is for visual user comfortable. The recommendation is if one computer with a big screen to can view all graphical interface elements.

The Fig. 11 shows the position evolution for the end effector in the coordinates (x, y, z). Also presents the user references provided with your hand using a kinect device. It should be noted that this is just an experiment. The platform allows the development of several controllers in order to improve the results according with the time delay over the communication channel. This paper tries to focus in the development of the platform and not the controllers.

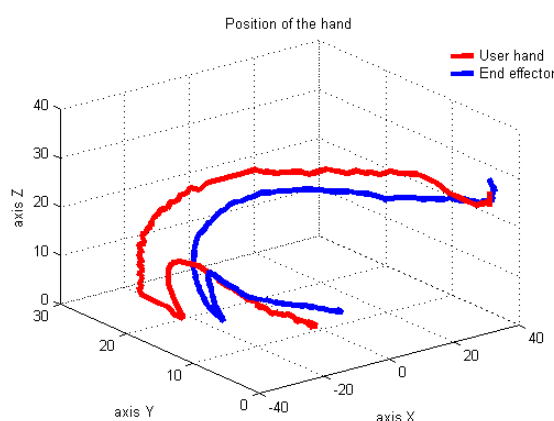


Fig. 11. Experiment using the platform with kinect device.

## 6 Conclusions

This structure is characterized by an easy replicate.

The prior robot simulations allowed avoiding mistakes in its building. These simulations enables calculating the robot workspace, select the appropriate actuators, the kinematics and dynamic behavior.

The proposed platform allows developing several practices in: automation, robot kinematic control, servo-vision using the camera IP or kinect device, neuro-signals processing with the EPOC emotive device, brain control, teleoperation and others.

The use of devices such as: kinect and EPOC emotive motivate students to work in robotic projects.

## References:

- [1] Bauer, S.; Wasza, J.; Haase, S.; Marosi, N.; Hornegger, J., "Multi-modal surface registration for markerless initial patient setup in radiation therapy using microsoft's Kinect sensor," *2011 IEEE International Conference on Computer Vision Workshops (ICCV Workshops)*, pp.1175-1181, 6-13 Nov. 2011
- [2] Frati, V.; Prattichizzo, D.; "Using Kinect for hand tracking and rendering in wearable haptics," *2011 IEEE-World Haptics Conference (WHC)*, pp.317-321, 21-24, 2011
- [3] Gallo, L.; Placitelli, A.P.; Ciampi, M., "Controller-free exploration of medical image data: Experiencing the Kinect," *2011 24th International Symposium on Computer-Based Medical Systems (CBMS)*, pp.1-6, 27-30 June 2011
- [4] Ganganath, N.; Leung, H., "Mobile robot localization using odometry and kinect sensor," *2012 IEEE International Conference on Emerging Signal Processing Applications (ESPA)*, pp.91-94, 12-14 Jan. 2012
- [5] Leyvand, T.; Meekhof, C.; Yi-Chen Wei; Jian Sun; Baining Guo, "Kinect Identity: Technology and Experience," *Computer*, vol.44, no.4, pp.94-96, April 2011
- [6] Rakprayoon, Panjawee; Ruchanurucks, Miti; Coundoul, Ada, "Kinect-based obstacle detection for manipulator," *2011 IEEE/SICE International Symposium on System Integration (SII)*, pp.68-73, 20-22 Dec. 2011
- [7] Ruther, M.; Lenz, M.; Bischof, H., "µNect: On using a gaming RGBD camera in micro-metrology applications," *2011 IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, pp.52-59, 20-25 June 2011
- [8] Schonauer, Christian; Pintaric, Thomas; Kaufmann, Hannes; Jansen - Kosterink, Stephanie; Vollenbroek-Hutten, Miriam, "Chronic pain rehabilitation with a serious game using multimodal input," *2011 International Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, pp.1-8, 27-29, 2011.
- [9] Stowers, J.; Hayes, M.; Bainbridge-Smith, A., "Altitude control of a quadrotor helicopter using depth map from Microsoft Kinect

sensor," *2011 IEEE International Conference on Mechatronics (ICM)*, pp.358-362, 13-15 April 2011

- [10] Ranky, G.N.; Adamovich, S., "Analysis of a commercial EEG device for the control of a robot arm," Bioengineering Conference, Proceedings of the 2010 IEEE 36th Annual Northeast, pp.1-2, 26-28 March 2010
- [11] Velardo, C; Dugelay, J; Paleari, M; Ariano, P, "Building the space scale or how to weigh a person with no gravity," *2012 IEEE International Conference on Emerging Signal Processing Applications (ESPA)*, pp.67-70, 12-14 Jan. 2012
- [12] Vourvopoulos, A.; Liarokapis, F., "Brain-Controlled NXT Robot: Tele-operating a Robot through Brain Electrical Activity, "2011 Third International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES), pp.140-143, 4-6 May 2011