Holonomic Platform and Six DOF Manipulator Robot Through Virtual Reality Devices

Cristhain A. Cristancho, Angelica Florez C, Hernando Leon Rodriguez

Industrial Engineering Department
Nueva Granada Military University
Bogotá, Colombia

Abstract--This paper describes the design and construction of a holonomic robot platform and a manipulator robot arm with 6 degree of freedom on top of the platform. The project explains how its work, made and control considering that the system uses several types of ways to be controlled. The robotic system is the mixture of three omni-wheels mobile platform to keep the robot stable and a modular 6 DOF articulate robot arm. The project had develop some novel control features like control wirelessly via USB throw a master servo Board; it has a graphic user interface developed in 3D virtual environment which shows all its different movements, battery level and manual control. Finally, it has some other devices to be manipulated like Wii remote control and a one 5DT Data Globe.

Keywords: holonomic robot, manipulator arm, mobile platform, 3D virtual environment, wii remote, 5DT glove.

I. Introduction

Develop applications in the field of robotics has an important problem to solve and it is the desire to implement autonomous robots with the ability to explore unknown places, execute tasks of high risk like defuse explosives or dangerous tasks for human workers. Most of autonomous robots are designed to do actions previously programmed or work in known environments, it is very useless when the robots needs to disable bombs or inspect unknown and hazardous places. Because of this it is necessary developing teleoperated systems that allow a full control on the robot in real environments.

When a robot is driven remotely, the operator generally suffer of some stress, it depends on the task that he is doing, especially when the work is about explosives. It occurs because the error in the mission must be zero; otherwise the operator can produce an explosion and lose the robotic system valued at thousands of dollars. To solve this, a mobile manipulator robot was developed. It is a prototype that allows users to test different techniques of control for the articulated arm and mobile platform that can be applied to a real explosive disposal robot. Also, the robot has the option to implement many ways of teleoperation. It helps to experiment all possible techniques and choose the best for each work of the robot. Additionally, a virtual reality environment was created. It reproduces the real movements of the robots and a scene that simulate a normal situation of exploration. The virtual environment is used to design and consider futures visualization systems that can be implemented on the robot. Another application of this VR environment is a simulator, it offers the possibility to train the operators and improve the skills to drive the robot. See figure 1.

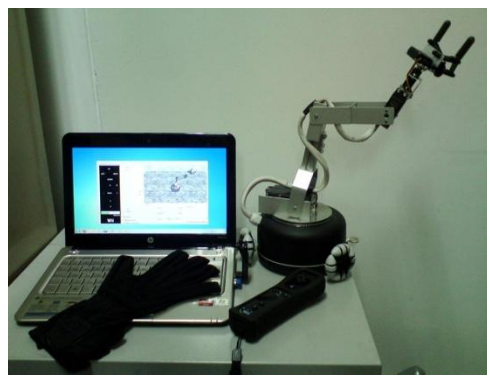

Figure 1: holonomic platform, 6 DOF manipulator and teleoperation devices

The mechanical design of the robot is introduced in section 2, in this one the principal parts and subcomponents are described. In the next section, a mathematical model was established for the articulated arm trough the forward kinematics and another model for the mobile platform. The models allow knowing all variables and parameters required to develop control algorithms. The sections 4 and 5 describe the electronic and software design necessary to communicate the control device with the PC and the robot. Finally the teleoperation methods and the virtual reality environment implemented are described in the last section.

II. Mechanical Design

The workspace of a robot is defined as all possible places that can reach its end effector or gripper. This space depends on the number of degrees of freedom and the transnational and rotational mechanical constraints that it has [1]. There are different kinds of configurations for a robot, the more commons are, cartesian, cylindrical, scara and anthropomorphic. For this robot it is used an anthropomorphic configuration with five degrees of freedom, three rotational movements for each joint in the robotic arm (shoulder, elbow and wrist) and two cylindrical, one for the base and the other one for the roll movement of the end effector. This configuration was chosen to have a large workspace and because it is not going to support heavy loads; for this last reason, it was not necessary to use a transmission system to move the arm, each joint has coupled a motor, as an actuator see figure 2.

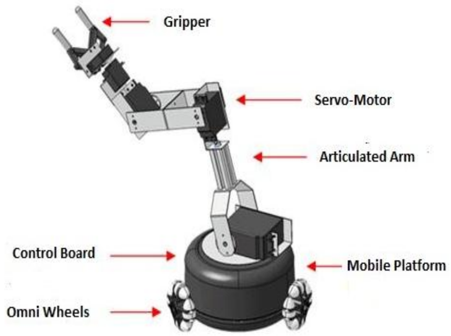

Figure 2: Main components of the 6 DOF manipulator robot.

Developing a mobile platform for the manipulator is an important skill for the robot, because it is the way to move it around different environments. There are three methods of locomotion system, wheeled locomotion, legged locomotion and skid locomotion. The one used is the wheeled locomotion, because the construction is very easy and it supports heavy loads.

There are different ways to build a mobile platform using a wheeled locomotion; It is possible to use two, three or more wheels, and different types of them in diverse configurations. In this case it was built using three omni-wheels, situated in a triangular way, with 120° degrees of separation between each one, to ensure an excellent stability because all the wheels have a direct contact with the flat surface. The omni-wheels are characterized by rollers located outside at 90° degrees of the main axis of the wheel. These types of wheels allow the mobile platform to move in any direction in any instant of time, which means in a holonomic way, but in the other hand they have a big inconvenient because the rollers material is a polymer that does not have too much adherence causing loses of friction during the movement.

A. Materials

The simulations made with Delmia software to analyze the inertia and the torques supported by each joint, help to determine the materials that must be used to build the robotic arm. The material chose was sheets of anodized aluminium, because it has low density and is very resistant, so in that way first of all it is going to resist the torque produced by each link of the manipulator and the actuators do not have to do a big effort to move the structure. In the other side, a plastic cylindrical structure was used to build the mobile platform, it has an axial needle roller that allows one degree of freedom in the base around z axis and a small compartment that stores and protects the electronic components of external environment.

B. Actuator

Nine Hi-TECH servomotors were used to control the movements of the robot, because they have the enough force and torque to realize that job. Each joint of the robotic arm and the wheels of the mobile platform has a servomotor. The figure 3 shows the principal components of a servomotor.

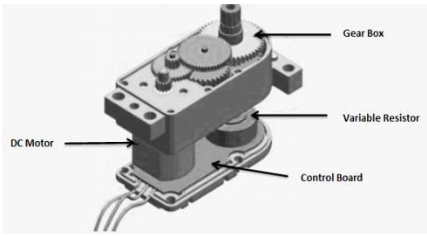

Figure 3: Internal structure of a servomotor

A servomotor has a DC motor with a reduction step that generates more power and torque, a variable resistance to sense the angle position of the motor and a control board to process and emit the signal to reach the desire angle. The servomotor angle is controlled by a PWM signal with a duty cyclerangingfrom1.2ms to 2 ms [4].

The advantages of the servomotor are:

- The feedback voltage of the servomotor is used to control the position of it and it is not necessary to use an encoder like a DC motor.
- They have high torque and inertia
- They have a mechanic limit, that allows the servomotor to rotate from 0° to 180° degrees, so it is not necessary to design mechanical limits on the articulated arm

C. Model Simulation

The figure 4 shows the design of the mobile manipulator robot developed in the software CATIA. The model is an approach to the real robot, and can be used to know different variables like the inertia, center of mass and the torques supported by each joint. These values will be used to estimate the construction materials and the actuators of the robot.

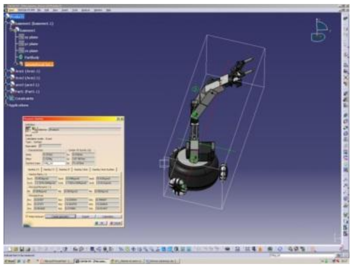

Figure 4: 3D Design Mobile Manipulator Robot 3D Design, CATIA

III. Forward Kinematics Analysis

A. Arm Kinematic

The forward kinematics problem is to determinate the position and orientation of the end effector, given the joint values and the geometrical parameters of the robot in relationship with a local frame. To determine the relationship between the position and orientation with respect a local frame is necessary to define a homogenous transformation matrix denoted by T. This matrix will be function of the joints coordinates and could be found trough the Denavit-Hartenber algorithm [3].

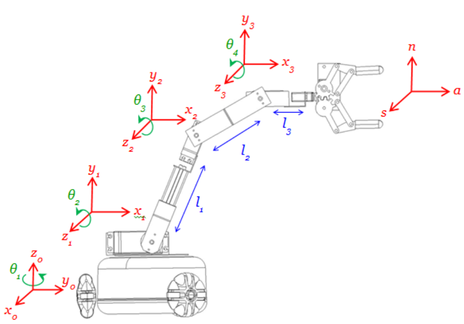

Figure 5: Kinematic coordinate system of the manipulate arm

Figure 5 illustrates the attaching frames to links in the manipulator arm. The arm is composed by four rotational joints; shoulder, elbow and wrist rotate on the same axis and orientation, but the base has a different orientation and is necessary to rotate its frame 90° to line up all axes.

The kinematics representation and parameters of the manipulator arm are shown in the Table 1. The table is composed by two parameters for the links and other two for the joints, θ_n is the joint angle and is the only variable value, α is the twist angle, a_n is the link length and d_n the link offset.

Axis (Joint)	Joint		Link	
	Angle (θ_n)	Distance (a_n) [mm]	Length (d_n)[mm] - fixed -	Twist angle (α_n)
1 (Base)	θ_1	0	0	$\pi/2$
2 (Shoulder)	θ_2	l_1	0	0
3 (Elbow)	θ_3	l_2	0	0
4 (Wrist)	θ_4	l_3	0	0

Table 1: D-H Parameter of the manipulator arm.

Given a position to the gripper or end-effector, the robot software generates a reference signal to the control system. Through the kinematics matrix the system calculates the values of the angles for each joint that permit achieve the position and orientation given by the reference signal. The values of the angles are converted by software to generate control signals for the actuators to move the mechanical arm.

Using the D-H parameter of the manipulator arm, the transformation matrices were obtained:

$$A_1^0 = \begin{bmatrix} C_1 & 0 & S_1 & 0 \\ S_1 & 0 & -C_1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_2^1 = \begin{bmatrix} C_1 & -S_1 & 0 & l_1C_2 \\ S_2 & C_2 & 0 & l_1S_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_3^2 = \begin{bmatrix} C_3 & -S_3 & 0 & l_2C_3 \\ S_3 & C_3 & 0 & l_2S_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_4^3 = \begin{bmatrix} C_4 & -S_4 & 0 & l_3C_4 \\ S_4 & C_4 & 0 & l_3S_4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2.1)$$

The forward kinematics solution of the arm is the product of the four matrixes shown before:

$$A_4^0 = \begin{bmatrix} n_x & O_x & a_x & d_x \\ n_y & O_y & a_y & d_y \\ n_z & O_z & 0 & d_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2.2)$$

Where:

$$n_x = C_1C_2C_3C_4 - C_1C_4S_2S_3 - C_1C_2S_3S_4 - C_1C_3S_2S_4$$
$$n_y = C_2C_3C_4S_1 - C_4S_1S_2S_3 - C_2S_1S_3S_4 - C_3S_1S_2S_4$$
$$n_z = C_3C_4S_2 - C_2C_4S_3 - S_2S_3S_4 - C_2C_3S_4$$

$O_x = -C_1C_2C_3S_4 + C_1S_2S_3S_4 - C_1C_2C_4S_3 - C_1C_3C_4S_2$
$O_y = -C_2C_3S_1S_4 + S_1S_2S_3S_4 - C_2C_4S_1S_3 - C_3C_4S_1S_2$
$O_z = -C_3S_2S_4 - C_2S_3S_4 - C_4S_2S_3 - C_2C_3C_4$
$a_x = S_1$
$a_y = -C_1$
$d_x = C_1C_2C_3C_4l_3 - C_1C_4S_2S_3l_3 - C_1C_2S_3S_4l_3 - C_1C_3S_2S_4l_3 + C_1C_2C_3l_2 - C_1S_2S_3l_2 + C_1C_2l_1$
$d_y = C_2C_3C_4S_1l_3 - C_4S_1S_2S_3l_3 - C_2S_1S_3S_4l_3 - C_3S_1S_2S_4l_3 + C_2C_3S_1l_2 - S_1S_2S_3l_2 + C_2S_1l_1$
$d_z = C_3C_4S_2l_3 + C_2C_4S_3l_3 - S_2S_3S_4l_3 + C_2C_3S_4l_3 + C_3S_2l_2 + C_2S_3l_2 + S_2l_2$

The following table explains the symbols used in the before equations:

$C_1 = \cos\theta_1$	$S_1 = \sin\theta_1$
$C_2 = \cos\theta_2$	$S_2 = \sin\theta_2$
$C_3 = \cos\theta_3$	$S_3 = \sin\theta_3$

Table 2: Symbols used in the equations

B. *Mobile Kinematics*

To describe the movements of the mobile platform is necessary to know the basic variables used for the system control like angular positions and angular velocities [2]. Therefore, to found these variables a kinematical model was developed for a triangular mobile platform with omni-wheels. The model starts defining a global frame [x,y] (see figure 6) which represents the environment of the robot. The position and orientation of this global frame is described as (x, y, θ) and the angular velocities can be represented as$(\dot{x},\dot{y},\dot{\theta})$. Also it's necessary to define a local frame $[X_L, Y_L]$ that is attached to the robot and coincides with the center of gravity of the mobile platform. The omniwheels are located at an angle $a_i\ (i = 1,2,3)$ relative to the local frame. Each omniwheel is separated 120° form the other one and the values of the angles are $a_1 = 0°,\ a_2 = 120°, a_3 = 240°$ counting degrees in clockwise direction as positive.

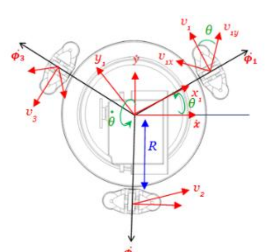

Figure 6: Kinematic diagram of the mobile platform

The translational velocities of the wheels v_i determine the global velocity of the robot in the environment $(\dot{x},\dot{y},\dot{\theta})$ and vice versa. This velocity v_i can be divided in two parts; the translational and the rotational one.

$$v_i = v_{trans,i} + v_{rot} \tag{2.3}$$

The translational velocity of the wheels can be described like a unit vector $v_{trans,i}$ onto the velocity vectors $\dot{x}$ y $\dot{y}$ as shown in Figure 7.

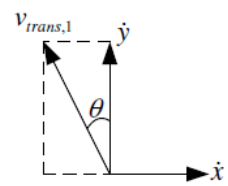

Figure 7: translational velocity in the center of the wheel.

$$v_{trans,1} = -\sin(\theta)\dot{x} + \cos(\theta)\,\dot{y} \tag{2.4}$$

The equation (2.5) can be generalized for all wheels taking in consideration that the vector v_i is positioned at an offset of$(\theta + a_i)$.

$$v_{trans,i} = -\sin(\theta + a_i)\,\dot{x} + \cos(\theta + a_i)\,\dot{y} \tag{2.5}$$

The rotational velocity $v_{rot}$is given by:

$$v_{rot} = R\dot{\theta} \tag{2.6}$$

Where: R is the distance from the center of gravity of the robot to the wheels along radial path.

Replacing the generalized values of the velocities in equation (2.5), the general form of v_i is obtained.

$$v_i = -\sin(\theta + \alpha_i)\,\dot{x} + \cos(\theta + \alpha_i)\,\dot{y} + R\dot{\theta} \tag{2.7}$$

Having attached the translational velocity of the wheels to the global velocity of the mobile platform, it's necessary to found the translational velocity of the center in relation with the angular velocity of the wheels$\dot{\phi}$. It can be determined through:

$$v_i = r\dot{\phi}_i \tag{2.8}$$

Where r is the radius of an omni-wheels, and replacing equation (2.8) in (2.7) the value of $\dot{\phi}$ is obtained.

$$\dot{\phi}_i = \frac{1}{r}(-\sin(\theta + \alpha_i)\,\dot{x} + \cos(\theta + \alpha_i)\,\dot{y} + R\dot{\theta} \tag{2.9}$$

The equation (2.7) can be transformed to matrix representation:

$$\dot{\phi} = J_{inv}\dot{u} \tag{2.10}$$

Where J_{inv} is the inverse Jacobian of the mobile platform that provides a direct relation between the angular velocities of the wheels $\dot{\phi}$ and the global vector of velocities $\dot{u}$.

$$\dot{\phi}_{1}=(-\sin(\theta)\cos(\theta)\,\dot{x}_L+\cos^2(\theta)\,\dot{y}_L+R\dot{\theta})/r$$
$$\dot{\phi}_{2}=(-\sin(\theta+\alpha_2)\cos(\theta)\,\dot{x}_L+\cos(\theta+\alpha_2)\cos(\theta)\,\dot{y}_L+R\dot{\theta})/r$$
$$\dot{\phi}_{3}=(-\sin(\theta+\alpha_3)\cos(\theta)\,\dot{x}_L+\cos(\theta+\alpha_3)\cos(\theta)\,\dot{y}_L+R\dot{\theta})/r$$

IV. Electronic Design

"Pololu Master Servo controller" is a controlled board, as it names says. It is used to send the PWM signal corresponding to move each servomotor to an achieve angle. These boards have high resolution and precision; they allow configuring the velocity and width of the signal emitted and have the possibility to work with each servomotor in a parallel way, because all the channels are independent.

It also has a USB communication that allows using a "Wireless USB kit with Transmitter and Receive" module to send and receive the data signal that controls the servomotor from the master computer. The communication devices have a transmission frequency of 3.168 to 4.752 GHz and it works in a distance range of 15m.

V. Software

A virtual environment software was developed using C# languages to visualize the 3D model of the robot and reproduce its real movements, to have a complete control of the teleoperation modes (manual, WiiMote and 5DT VR glove) and to realize all the communication between the computer and the master servo controller that move each actuator of the mobile manipulator robot. The virtual environment and the user interface were created using several software packages. See figure 8.

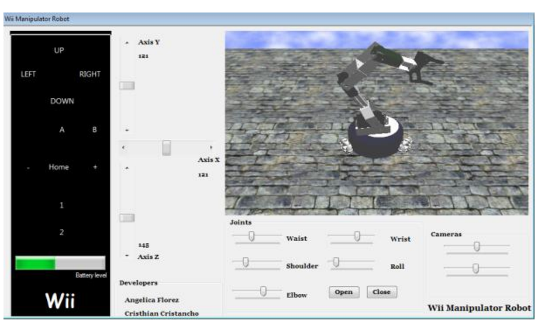

Figure 8: Virtual reality environment.

The first step to create the VR environment was to save the 3D model designed in CATIA in STL format. This format allows modified the parts of the robot in Blender, here, the colours, textures and rotation points can be adjusted. The next step is export the model to C# trough the MOGRE libraries and create the variables that permit the control of the joints in that way the 3D Model is ready to reproduce the movements of the robot. After creating the 3D model in the user interface, it is configured all about the communication between the computer and the robot, sending and receiving information from the pololu board to synchronize the movements of the mobile manipulator robot and the VR environment.

Finally the signal of the Wii mote control and VR glove to move the robot trough the hand movement is received and processed, to send the corresponding orders to the robot and the 3D model at the same time. The software structure is shown in figure 9.

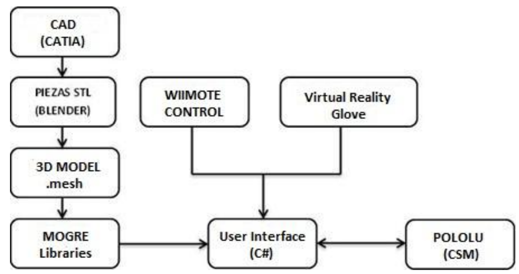

Figure 9.Software programming architecture

VI. Control system and Teleoperation

There are different methods to make a control system with a teleoperation mode. In this case it is going to be used a Wiimote control and a 5DT data glove with a virtual environment.

In our days many people know and use a Wii mote to have fun and play different videogames; but this device also could be used to control a mobile manipulator robot using the signal from the accelerometer in the three axes (x,y,z) that it has and the different buttons. Another characteristic of this control is that it has two communication systems, the infrared and the Bluetooth communication; in this case, it is going to be used the last one to send the information to the computer. The 5DT Data Glove is designed to satisfy the stringent requirements of modern Motion Capture and Animation Professionals. It is also used in the robotic area to move the joints of a robotic arm, with the signal from the sensors that measure finger flexure of the user's hand or use the different gestures of it to move all the joints at the same time, following a path. The system interfaces with the computer via a USB cable.

In the virtual environment, there are predetermined paths that the robot and the 3D model follow at the same time, when any of the two methods of teleoperation indicate them. It also has a toolbox to select the control system. Figure 10 describes the two methods used to teleoperate the mobile manipulator robot. The first one is using a Wii mote that works in a wireless way to send the information to the computer when a button is pressed and it is moved to activate the accelerometer sensor at the same time. The second one is the 5DT Data Glove that has a USB communications to send the signal when a finger is move or when the user is doing a gesture. When the computer received the information it is processed in the virtual environment, so in that way the robot and the 3D model realized the corresponding movements.

The most appropriate teleoperation system most to this robot, is the one with de 5DT VR glove, because it offers a better control on it to manipulate each joint of the articulated arm in the different tasks that it is going to realize like defusing bombes or exploring unknown places, which are chores that must be do carefully with cautiously movements.

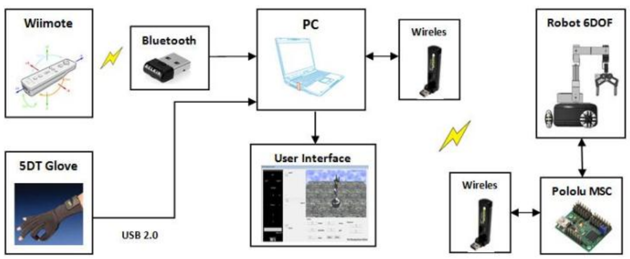

Figure 10.Teleoperation system for 6DOF Robot manipulator

VII. Conclusions

The development of tele-operated system in the field of robotics offers different ways of control that can be used on the manipulator. It helps to solve tasks where the human can be in danger or reach inaccessible places. The first system developed was with a Wii control, it allows the user interact easily with the robot and see another applications of this device. Moreover, the virtual reality glove gives the opportunity to reproduce the finger's movements in the robotic arm and feel the sensation of immersion in a virtual scene trough the virtual reality environment.

A mobile manipulator robot with six degrees of freedom has a big work space that allow the end-effector or gripper of the robot achieve many positions in different ways, also, the mobile platform gives additional applications to the robot , for example an anti-explosives or a house cleaner robot.

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