Kinematic Modeling of a Humanoid Robot RH-ARP in a Virtual Environment

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ABSTRACT: *We have already proposed a new approach to modeling the humanoid robot [1], the direct and inverse geometric model of the humanoid robot RH-ARP [2] This result complements the first study and is used for the practical realization of this prototype. The work presented in this paper is the kinematic modeling of robot RH-ARP, with 18 degrees of freedom (DOF), three degrees of freedom in each arm and six degrees of freedom per foot.*

Keywords: Humanoid Robot, Kinematic Modeling, Virtual Reality Modeling Language

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1. Introduction

In this article we focus on the direct kinematic description of humanoid robots,that is to say, the connection between the position and orientation of the end effector of the robot and the joint variables.Then we will apply our humanoid robot has 18 degrees of freedom. We will limit to the case where each joint has a single degree of freedom of rotation. To make the kinematic description of our humanoid we associate a reference to each part of the robot (half humanoid robot) and describe their relative position using the Denavit-Hartenberg parameters. The kinematic description of the complete robot is then obtained easily by induction.

2. Position of the Problem

The description of the humanoid robot in the form of mathematical equations (geometric patterns, kinematics, dynamics, etc ...), allowto engender robot movements needed to complete a task in a given environment.

Obtaining these different models is not easy, the difficulty varies depending on the complexity of the kinematics of the articulated chain, entering into account the number of degrees of freedom, the type of joints, as well as the type of the kinematic chain that can be opened simply, tree or closed.

The work we present in this article is the kinematic model of the humanoid robot RH-ARP [1]. Consists of 18 DOF whose height is equal to 170 cm, we proposed a new approach [2] modeling humanoid robot.

After having established a state of the art that we have developed, we find several modeling techniques proposed by different authors In the work done by "*M.ARBULU* " [3] & "*Carlos* [4]",They divided the body of the humanoid robot RH-0 in two independent parties (half-humanoid) manipulators. and they considerer each half-humanoid as a open joint chain.

"*Min-Chan Hwang*" [5] for geometric modelling and kinematics of a humanoid robot the authors considered each leg of the robot manipulator as anindependent, and they calculated the geometric model and itskinematic model. For this we consider the humanoid robot assimple joint chain.

In the work done by "*J.de Lope*" [6], in the direct kinematics of the humanoid PINO robot as regards what the relative position and orientation of one foot from the other is solved easily considering a model as a robotic chain of links interconnected to one another by joints. The first link, the base coordinate frame, is the right foot of the robot. We assume it to be fixed to the ground for a given final position or movement, where the robot global coordinate frame will be placed. The last link istheleftfoot, which will befreetomove.

In theworkdoneby "*Muhammad. A*" [7], the authors set two bases coordinate frames *B*1 and *B*2 for the Hubo KHR-4 humanoid robot. *B*1 is established at the center of the neck and is the reference coordinate frame for the arms and the head, and B2 is the reference coordinate frame for the legs. *B*2 is linked to *B*1 through a waist joint, and there is a simple link transformation matrix between *B*1 and *B*2. As a result, *B*1 is considered to be the global base coordinate frame for the whole robot.

In the work [1], [2] the authors consider that the left hand and the right foot as a single joint chain, and the right hand with his left foot as a second single joint chain

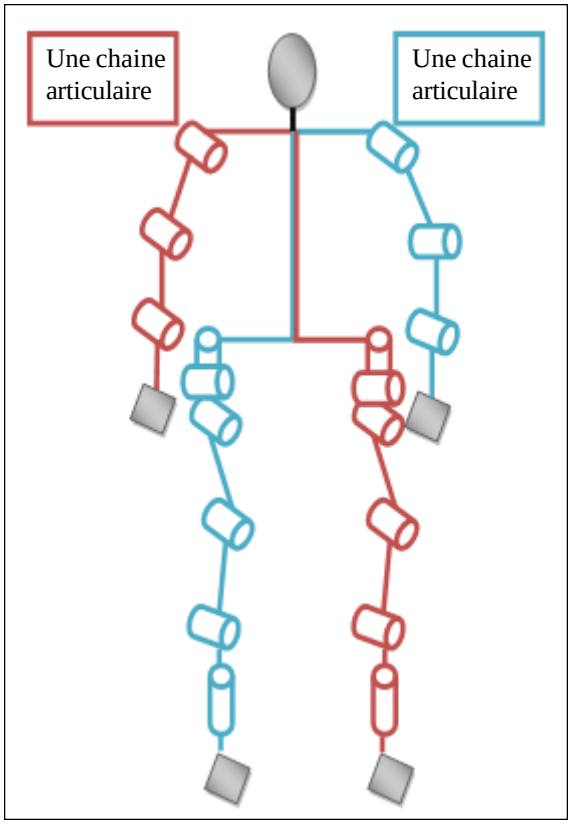

Figure 1. Model suggestedfor prototype RH-ARP

3. Direct Geometrical Modeling of the RH-ARP

We use the notation of Denavit Hartenberg Modified to havethe representation of our prototype and the matrix of transformation

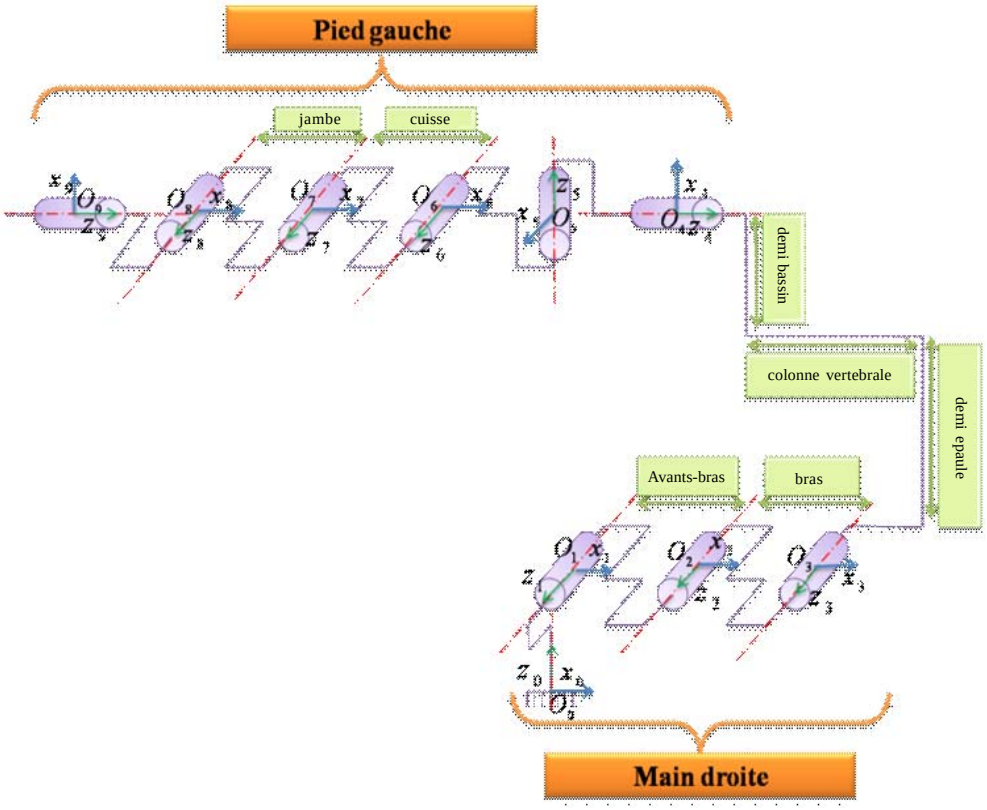

Figure 2. Direct geometrical modeling of the RH-ARP

4. The Direct Kinematics Model of OF RH-ARP

The calculation of direct kinematics is done is one deriving the homogeneous matrix of transformation when we have 3DOF or less or using the formula of composition speed when it is higher than 3 DOF.

Method of calculating of the velocity vector $\dot{X}$ of the effect or carried out by using a recurring formulation based on the theorem of composition speeds; there after we deduces Jacobian from the following matric relation:

$$\dot{X} = \begin{bmatrix} v_n \\ w_n \end{bmatrix} = [\tilde{J}_n] . [\dot{q}]$$

where V_n: The velocity vectorof the endrelative to thereference frame $\{R0\}$. w_n: The velocity vectorofinstantaneousrotation of theterminal with respectto the reference $\{R0\}$. Itexpressesin general V_n and w_n, or in the reference $\{Rn\}$, orin the reference $\{R0\}$.

we put

$$C_i = \cos(theta_i)$$

$$S_i = \sin(theta_i)$$

knowing that

$C_{i+j} = \cos(theat_i) * \cos(theta_j) - \sin(theta_i) * \sin(theta_j)$

$S_{i+j} = \cos(theat_i) * \sin(theta_j) + \sin(theta_i) * \cos(theta_j)$

Joint 0

It is supposed that the first body of the kinematic chain is fixed at a wall. therefore we have the speeds (the velocity Vector of the effector relative to the reference mark $\{R0\}$)

And (the velocity Vector of instantaneous rotation of theeffector relative to the reference mark {$R0$}) are equal to zero (the kinematic chain is fixed).

$$\vec{w}_0 = \vec{0}$$
$$\vec{V}_0 = \vec{0} \quad (1)$$

Joint 1

The body (1) represents the articulation of the wrist of the right hand

$$\vec{w}_1 = \vec{w}_0 + \vec{\sigma}_1 . \dot{q}_1 . \vec{z}_1 = \begin{bmatrix} 0 \\ 0 \\ \dot{q}_1 \end{bmatrix}$$
$$\vec{V}_1 = \vec{V}_0 + w_0 \wedge \overrightarrow{O_0 O_1} + \sigma_1 . \dot{q}_1 . \vec{z}_1 = \vec{0} \quad (2)$$

Joint 2

The body (2) represents the articulation of the elbow

$$\vec{w}_2 = \vec{w}_1 + \vec{\sigma}_2 . \dot{q}_2 . \vec{z}_2 = {}^2\mathrm{R}_1 * \begin{bmatrix} 0 \\ 0 \\ \dot{q}_1 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{q}_2 \end{bmatrix} * \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \dot{q}_1 + \dot{q}_2 \end{bmatrix}$$

$$\vec{V}_2/R_1 = \vec{V}_1 + \vec{w}_1 \wedge \overrightarrow{O_1 O_2} + \sigma_2 . \dot{q}_2 . \vec{z}_2 = \vec{0} + \begin{bmatrix} 0 \\ 0 \\ \dot{q}_1 \end{bmatrix} \wedge \begin{bmatrix} 25 \\ 0 \\ 0 \end{bmatrix} + 0 = \begin{bmatrix} 0 \\ 25\dot{q}_1 \\ 0 \end{bmatrix}$$

$$\vec{V}_2/R_2 = {}^2R_1 * \vec{V}_2/R_1 = \begin{bmatrix} 25\dot{q}_1 S_2 \\ 25\dot{q}_1 C_2 \\ 0 \end{bmatrix} \quad (3)$$

Joint 3:

The body (3) represent the articulation of the wrist

$$\vec{w}_3 = \vec{w}_2 + \vec{\sigma}_3 . \dot{q}_3 . \vec{z}_3 = {}^3\mathrm{R}_2 * \begin{bmatrix} 0 \\ 0 \\ \dot{q}_1 + \dot{q}_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{q}_3 \end{bmatrix} * \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \dot{q}_1 + \dot{q}_2 + \dot{q}_3 \end{bmatrix}$$

$$\vec{V}_3/R_2 = \vec{V}_2 + \vec{w}_2 \wedge \overrightarrow{O_2 O_3} + \sigma_3 . \dot{q}_3 . \vec{z}_3 = \begin{bmatrix} 25\dot{q}_1 S_2 \\ 25\dot{q}_1 C_2 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{q}_1 + \dot{q}_2 \end{bmatrix} \wedge \begin{bmatrix} 32 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 25\dot{q}_1 S_2 \\ 32(\dot{q}_1 + \dot{q}_2) + 25\dot{q}_1 C_2 \\ 0 \end{bmatrix}$$

$$\vec{V}_3/R_3 = {}^3R_2 * \vec{V}_3/R_2 = \begin{bmatrix} S_3(32(\dot{q}_1 + \dot{q}_2) + 25\dot{q}_1 C_2) + 25\dot{q}_1 C_3 S_2 \\ C_3(32(\dot{q}_1 + \dot{q}_2) + 25\dot{q}_1 C_2) - 25\dot{q}_1 S_2 S_3 \\ 0 \end{bmatrix} \quad (4)$$

$$\vec{V}_3/R_2 = \vec{V}_2 + \vec{w}_2 \wedge \overrightarrow{O_2 O_3} + \sigma_3 . \dot{q}_3 . \vec{z}_3 = \begin{bmatrix} 25\dot{q}_1 S_2 \\ 25\dot{q}_1 C_2 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{q}_1 + \dot{q}_2 \end{bmatrix} \wedge \begin{bmatrix} 32 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 25\dot{q}_1 S_2 \\ 32(\dot{q}_1 + \dot{q}_2) + 25\dot{q}_1 C_2 \\ 0 \end{bmatrix}$$

$$\vec{V}_3/R_3 = {}^3R_2 * \vec{V}_3/R_2 = \begin{bmatrix} S_3(32(\dot{q}_1 + \dot{q}_2) + 25\dot{q}_1 C_2) + 25\dot{q}_1 C_3 S_2 \\ C_3(32(\dot{q}_1 + \dot{q}_2) + 25\dot{q}_1 C_2) - 25\dot{q}_1 S_2 S_3 \\ 0 \end{bmatrix} \quad (5)$$

The bodies 4; 5; 6 represent the articulations of the hip.

Joint 4:

$$\vec{w}_4 = \vec{w}_3 + \bar{\sigma}_4 . \dot{q}_4 . \vec{z}_4 = {}^4\mathrm{R}_3 * \begin{bmatrix} 0 \\ 0 \\ \dot{q}_1 + \dot{q}_2 + \dot{q}_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{q}_4 \end{bmatrix} * \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 \end{bmatrix}$$

$$\vec{V}_4/R_3 = \vec{V}_3 + \vec{w}_3 \wedge \overrightarrow{O_3O_4} + \sigma_4 . \dot{q}_4 . \vec{z}_4 = \begin{bmatrix} S_3(32(\dot{q}_1 + \dot{q}_2) + 25\dot{q}_1 C_2) + 25\dot{q}_1 C_3 S_2 \\ C_3(32(\dot{q}_1 + \dot{q}_2) + 25\dot{q}_1 C_2) - 25\dot{q}_1 S_2 S_3 \\ 0 \end{bmatrix}$$

$$\vec{V}_4/R_4 = {}^4R_3 * \vec{V}_4/R_3$$

$$\vec{V}_4/R_3 = \vec{V}_3 + \vec{w}_3 \wedge \overrightarrow{O_3O_4} + \sigma_4 . \dot{q}_4 . \vec{z}_4$$

$$\vec{V}_4/R_4 = {}^4R_3 * \vec{V}_4/R_3 \tag{6}$$

$$\vec{V}_4/R_3 = \vec{V}_3 + \vec{w}_3 \wedge \overrightarrow{O_3O_4} + \sigma_4 . \dot{q}_4 . \vec{z}_4 = \begin{bmatrix} S_3(32(\dot{q}_1 + \dot{q}_2) + 25\dot{q}_1 C_2) + 25\dot{q}_1 C_3 S_2 \\ C_3(32(\dot{q}_1 + \dot{q}_2) + 25\dot{q}_1 C_2) - 25\dot{q}_1 S_2 S_3 \\ 0 \end{bmatrix}$$

$$\vec{V}_4/R_4 = {}^4R_3 * \vec{V}_4/R_3$$

$$\vec{V}_4/R_3 = \vec{V}_3 + \vec{w}_3 \wedge \overrightarrow{O_3O_4} + \sigma_4 . \dot{q}_4 . \vec{z}_4$$

$$\vec{V}_4/R_4 = {}^4R_3 * \vec{V}_4/R_3 \tag{7}$$

Joint 5:

$$\vec{w}_5 = \vec{w}_4 + \bar{\sigma}_5 . \dot{q}_5 . \vec{z}_5 = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\vec{w}_5 = \vec{w}_4 + \bar{\sigma}_5 . \dot{q}_5 . \vec{z}_5 = {}^5\mathrm{R}_4 * \begin{bmatrix} 0 \\ 0 \\ \dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{q}_5 \end{bmatrix} * \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} S_5(\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4) \\ C_5(\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4) \\ \dot{q}_5 \end{bmatrix}$$

$$\vec{V}_5/R_4 = \vec{V}_4 + \vec{w}_4 \wedge \overrightarrow{O_4O_5} + \sigma_5 . \dot{q}_5 . \vec{z}_5$$

$$\vec{V}_5/R_5 = {}^5R_4 * \vec{V}_5/R_4 \tag{8}$$

Joint 6:

$$\vec{w}_6 = \vec{w}_5 + \bar{\sigma}_6 . \dot{q}_6 . \vec{z}_6$$

$$\vec{V}_6/R_5 = \vec{V}_5 + \vec{w}_5 \wedge \overrightarrow{O_5O_6} + \sigma_6 . \dot{q}_6 . \vec{z}_6 \tag{9}$$

$$\vec{V}_6/R_6 = {}^6R_5 * \vec{V}_6/R_5$$

Joint 7:

Bodies 7 represent the articulations of the knee

$$\vec{w}_7 = \vec{w}_6 + \bar{\sigma}_7 . \dot{q}_7 . \vec{z}_7$$

$$\vec{V}_7/R_6 = \vec{V}_6 + \vec{w}_6 \wedge \overrightarrow{O_6O_7} + \sigma_7 . \dot{q}_7 . \vec{z}_7$$

$$\vec{V}_7/R_7 = {}^7R_6 * \vec{V}_7/R_6 \tag{10}$$

Bodies 8 and 9 represent the articulations of ankle

Joint 8:

$$\vec{w}_8 = \vec{w}_7 + \bar{\sigma}_8 . \dot{q}_8 . \vec{z}_8$$

$$\vec{V}_8/R_7 = \vec{V}_7 + \vec{w}_7 \wedge \overrightarrow{O_7O_8} + \sigma_8 . \dot{q}_8 . \vec{z}_8$$

$$\vec{V}_8/R_8 = {}^8R_7 * \vec{V}_8/R_7 \tag{11}$$

Joint 9:

$$\vec{w}_9 = \vec{w}_8 + \bar{\sigma}_9 . \dot{q}_9 . \vec{z}_9$$

$$\vec{V}_9/R_8 = \vec{V}_8 + \vec{w}_8 \wedge \overrightarrow{O_8O_9} + \sigma_9 . \dot{q}_9 . \vec{z}_9$$

$$\vec{V}_9/R_9 = {}^9R_8 * \vec{V}_9/R_8 \tag{12}$$

5. Calcul of the Jacobian

The correspondingJacobian matrixis denoted ${}^n[\tilde{J}_n]$ or ${}^0[\tilde{J}_n]$, respectively.

$$J_9^9 = \begin{bmatrix} \vec{V}_9/R_9 \\ \vec{w}_9 \end{bmatrix}$$

6. Results

The following program allows for the kinematic model of the prototype HR-ARP. We calculate the Jacobian half humanoid consists of the right hand and left foot. This kinematic chain contains 9ddl.

```
%%%%%%%%%%%%ModèleCinématiqueDirect%%%%%%
clc
clear all
close all
%%%%%%%%%%
w0 = [0; 0; 0]
    v0 = [0; 0; 0]
    %%%%%%%%%%%%
    q1p = sym('q1p');
    sigma_1 = 1;
theta1 = sym('theta1');
     alpha1 = pi/2;
     c1 = cos (theta1);
     s1 = sin (theta1);
ca1 = fix (cos (alpha1));
    sa1 = fix (sin (alpha1));
O0O1 = [0; 0; 0];
    T1 = [cos (theta1) – sin (theta1) 0; 0 0 –1; sin (theta1) cos (theta1) 0];
T1';
    z1 = [0; 0; 1];
```

$w_1 = T_1' * w_0 + \text{sigma_1} * q_1p * z_1$

$v_1 = v_0 + \text{cross}(w_0, O_0O_1)$

$V_1R_1 = T_1' * v_1$

%%%%%%%%%%%%%%%

$q_2p = \text{sym}('q_2p')$;

sigma_2 = 1;

$theta_2 = \text{sym}('theta_2')$;

$alpha_2 = 0$;

$c_2 = \cos(theta_2)$;

$s_2 = \sin(theta_2)$;

$ca_2 = \text{fix}(\cos(alpha_2))$;

$sa_2 = \text{fix}(\sin(alpha_2))$;

$O_1O_2 = [25; 0; 0]$;

$T_2 = [\cos(theta_2) - \sin(theta_2)\ 0; \sin(theta_2)\ \cos(theta_2)\ 0; 0\ 0\ 1]$;

T_2';

$z_2 = [0; 0; 1]$;

$w_2 = T_2' * w_1 + \text{sigma_2} * q_2p * z_2$

$v_2 = V_1R_1 + \text{cross}(w_1, O_1O_2)$

$V_2R_2 = T_2' * v_2$

Figure 3. The program of the kinematics of HR-ARP

This figure represents the result of the calculation of the elements of the matrix jacobiane V_n & w_n.

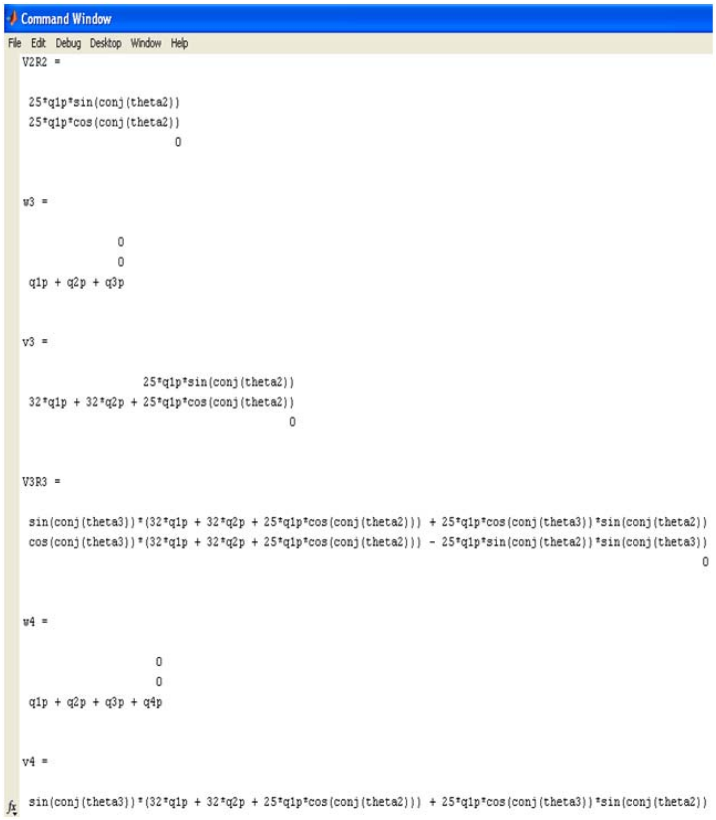

Figure 4.The program of the kinematic

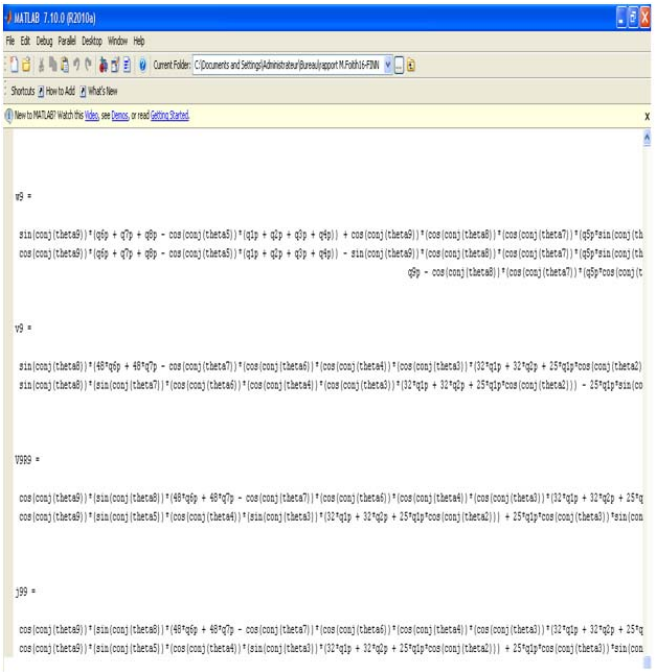

Figure 5. The jacobian matrix

This figure represents a portion of the matrix J99 jacobianeit can not appearon the screen. Sight of his importance size.

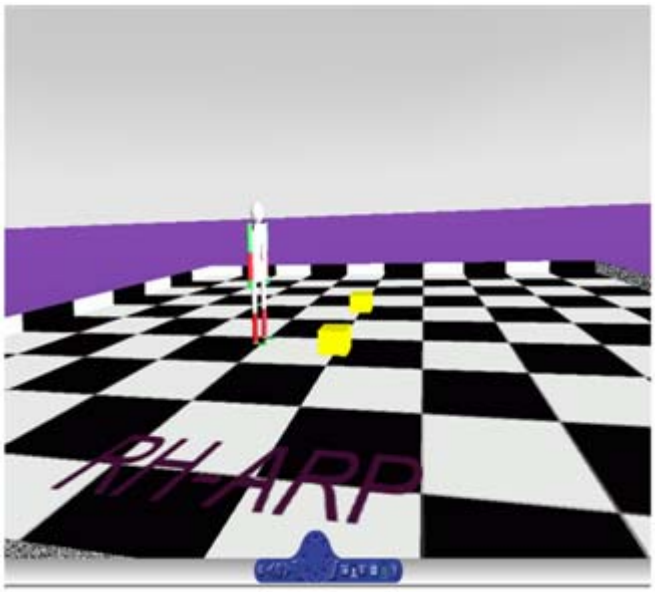

Figure 6. Modeling of RH-ARP with VRML

The figure precedent represents prototype RH-ARP designed in a virtual environment using a program (vrml) under matlab.

7. Conclusions

After a managing multiple resources and after synthesis we bring a new approach to modeling and control of our humanoid robot which is the originality of our work.

For this we modified the model by introducing new resolutions for programming direct and inverse geometric model, the direct

kinematic model and path planning.

In the last part of this work, we have applied our approach to a virtual system representing a humanoid robot. An architecture based on the Matlab software that allowed us to move the robot followed a trajectory.

At the end of this work we suggest the generation of the biped walking and the study of the practical stability of the latter. Thus we propose the integration of artificial vision for the path planning..

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