Analysis of Human Arm Joints and Extension of the Study to Robot Manipulator

Valentin Grecu, Nicolae Dumitru, and Luminita Grecu

Abstract— **The paper presents the analysis of human arm joints is carried out and the study is extended to the robot manipulator. This study will first focus on the kinematics of human upper arm which include the movement of each joint in shoulder, wrist, elbow and fingers. Those analyses are then extended to the design of a human robot manipulator. A simulator is built for Direct Kinematics and Inverse Kinematics of human upper arm. In the simulation of Direct Kinematics, the human joint angles can be inserted, while the position and orientation of each finger tips (end-effector) are shown. The simulation of human arm forward kinematics is performed through MATLAB Graphical User Interface and VRML. tained from kinematics analysis, the human manipulator joints can be designed to follow prescribed position trajectories**.

Index Terms —**Human Joints, Kinematics, Manipulators Robotics, Robot Dynamics.**

I. INTRODUCTION

This paper focuses on the kinematics analysis of human upper arm and extends it to the human manipulator.

Kinematics is the study of motion without regard to the forces that create it. The representation of the robot's end-effector position and orientation through the geometries of robots (joint and link parameters) are called Direct Kinematics. Using Direct Kinematics, the mathematical model is developed to compute the position and orientation of each fingertip (end-effector's) based on the given human joint position. Each human joint is considered as revolute joint. The homogenous transformation of the fingertip related to the base frame (arm upper limb) is formulated using Denavit-Hartenberg (D-H) method. [3]

Inverse Kinematics analysis is a formulation to compute a set of joint variables from the given end-effector or tool piece pose. In the present study, an articulated finger consists of a set of rigid segments connected with joints. Each finger joint angles will be computed by the given fingertip position and orientation. Varying the angles of the joints yields an indefinite number of configurations. Geometric approach will be used to solve this problem.

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Kinematics of the human body is concerned with formulating and solving for the translational and rotational position, velocity, and acceleration analysis problems for each human body segment of interest, for various real-world motions.

Forward kinematics calculates the pose (position and orientation) of each human body segment of interest given the joint angles. The forward kinematics is the problem of finding an end-effector or tool pose from a set of given joint angles. Inverse kinematics calculates the required joint angles given the current human body (or portion thereof) pose. Statics requires the positions and angles of each segment for static free-body diagrams. Dynamics requires the translational and rotational position, velocity, and acceleration variables for each human body segment, plus the CG translational accelerations, for dynamic free body diagrams.

Inverse dynamics calculates the joint torques given all translational and rotational kinematics terms through acceleration. Forward dynamics, a much harder mathematical problem, calculates the unknown kinematics terms given the joint torques; this requires the solution of coupled nonlinear differential equations.

Essentially this is a "force balance" approach, where we:
(a) determine accelerations by propagating from the base to the end-effector;
(b) apply Newton and Euler equations;
(c) determine required forces and torques by propagating from the end effector in to the base.

An alternative "energy balance" method exist for determining equations of motion for a manipulator was the Lagrangian method.

The next section presents the kinematics problems and solutions for a simplified model of the human arm, which also serves as a simplified model for the human leg (with different joint limits).

Manipulator dynamics is the manipulator motion that causes the torque and moments at the joint due to the externals loads that applied at the end effector, manipulator joint velocities, and accelerations. The Newton-Euler method is used to formulate the model. The external forces acting at the fingertip, and due to this, the force and moment transferred to each joint are estimated using the Newton-Euler method.

The design of the control system will be introduced here. A primary concern of a position control system is to automatically compensate for errors in knowledge of the parameters of a system, and to suppress disturbances which tend to perturb the system from the desired trajectory.

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II. THEORETICAL WORK

A. Direct Kinematics of Human Upper Arm

The human upper arm will be modeled by using Direct Kinematics principal.
The steps to solve the problems are: [1]
1. Attach an inertial frame to the human arm joint.
The reference frame is considered with its origin in the point situated at the middle of the scapular belt.
2. Attach frames to links, including the finger tip.

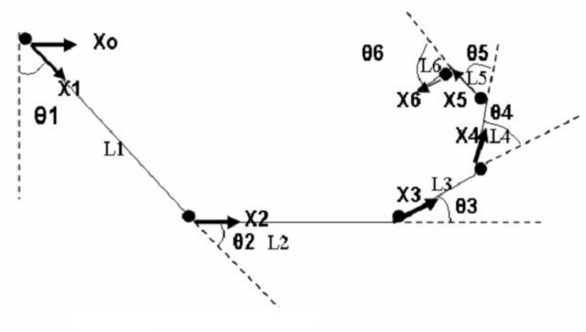

Fig. 1 Frames on each joint.

3. Write the Denavit-Hartenberg Table

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	0	L_1	0	θ_2
3	0	L_2	0	θ_3
4	0	L_3	0	θ_4
5	0	L_4	0	θ_5
6	0	L_5	0	θ_6
7	0	L_6	0	0

4. Determine the homogenous transformation between each frame by applying the general formula.

$$
{}^{i-1}_{i}T = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -s\alpha_{i-1} d_i \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & c\alpha_{i-1} d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

5. Apply the set of transforms sequentially to obtain a final overall transform.

$$
{}^{0}_{7}T = \begin{bmatrix} c_{1234567} & -s_{1234567} & 0 & L_1 c_1 + L_2 c_{12} + L_3 c_{123} + L_4 c_{1234} + L_5 c_{12345} + L_6 c_{123456} \\ s_{1234567} & c_{1234567} & 0 & L_1 s_1 + L_2 s_{12} + L_3 s_{123} + L_4 s_{1234} + L_5 s_{12345} + L_6 s_{123456} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

B. Inverse Kinematics of Human Fingers

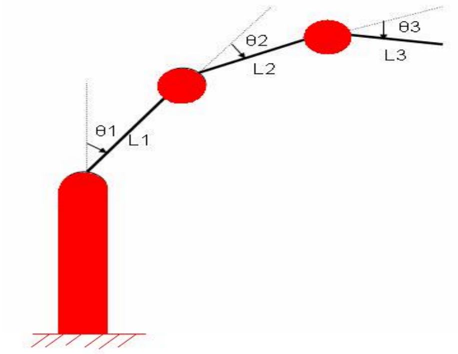

Fig. 2 Flexion Angles of Fingers

First of all we previously compute forward kinematics of the fingers. [2]

$$x = L_1 \cos\theta_1 + L_2 \cos(\theta_1 + \theta_2) + L_3 \cos(\theta_1 + \theta_2 + \theta_3)$$
(1)

$$y = L_1 \sin\theta_1 + L_2 \sin(\theta_1 + \theta_2) + L_3 \sin(\theta_1 + \theta_2 + \theta_3)$$
(2)

And we know that $\theta = \theta_1 + \theta_2 + \theta_3$ (3)

For inverse kinematics, we are given Cartesian coordinates, x, y, and ϕ. We will be finding the value for $\theta_1, \theta_2, \theta_3$.
And we are left with two equations and two unknowns θ_1, θ_2.

$$x - L_3 \cos\theta = L_1 \cos\theta_1 + L_2 \cos(\theta_1 + \theta_2) \quad (4)$$

$$y - L_3 \sin\theta = L_1 \sin\theta_1 + L_2 \sin(\theta_1 + \theta_2) \quad (5)$$

The variables in left side are all given, while the θ_1, θ_2 are unknown in this case.
The figure 1 shows the simplified 3-dof planar human arm model with an R joint at the shoulder, elbow, and wrist pitch motions. Note this will also serve as a simplified leg model, with the hip, knee, ankle joints, and appropriate lengths and joint limits substituted for the arm parameters. L_1 is the upper arm length, L_2 is the forearm length, and L_3 is the hand length. θ_1 is the absolute shoulder pitch angle, θ_2 is the relative elbow pitch angle, and θ_3 is the relative wrist pitch angle.
We use the following segment lengths (m):

Subject	L1 (upperarm)	L2 (forearm)	L3 (hand)
adult male	0.315	0.287	0.105
adult female	0.272	0.252	0.091

We use the following angle limits (degree same for both male and female):

Angle	Min	Max
θ_1	-140	90
θ_2	0	145
θ_3	-70	90

We simulate Forward Pose Kinematics for the entire range of motion from the minimum to maximum angle on each joint simultaneously in MATLAB program.

Given $\theta_1 = -135^0, \theta_2 = 90^0, \theta_3 = 45^0$, the unique FPK solutions are :

$$X_{male} = [x_H \quad y_H \quad \theta] = [0{,}085 \quad -0{,}426 \quad 0]$$

$$X_{female} = [x_H \quad y_H \quad \theta] = [0{,}077 \quad -0{,}371 \quad 0]$$

The results of this human arms FPK trajectory motion simulation are given on the next section.

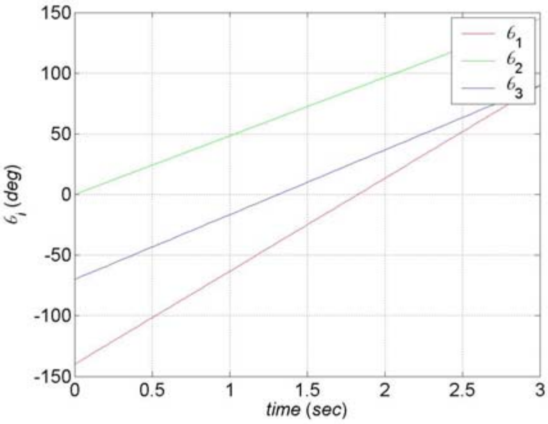

Fig.3. Input Angles

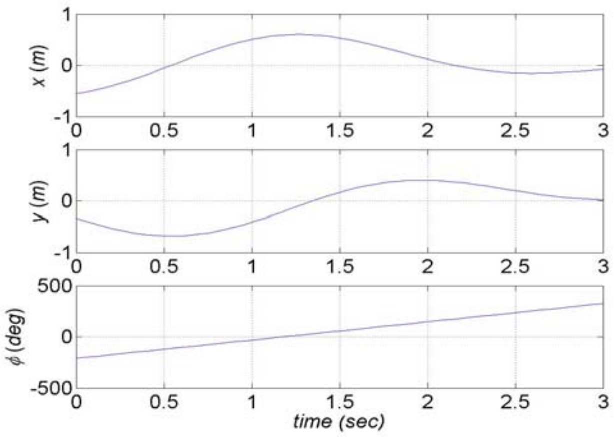

Fig.4 FPK Results (x, y, φ vs. t)

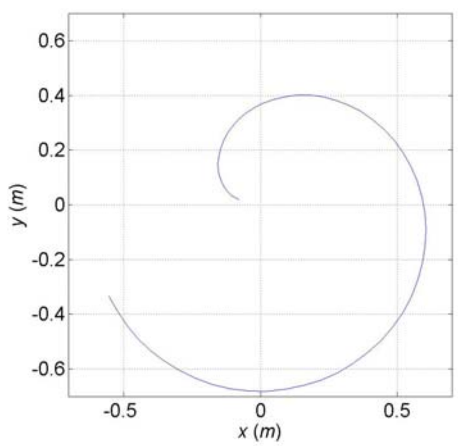

Fig.5 FPK Results (y vs. x)

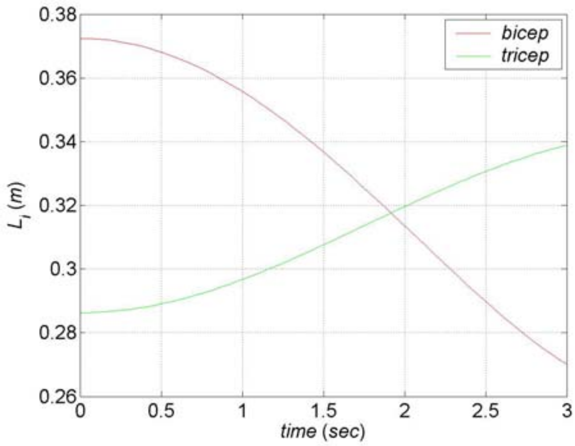

Fig.6 Simulated Muscle Lengths

C. Controller System of Robot Manipulator

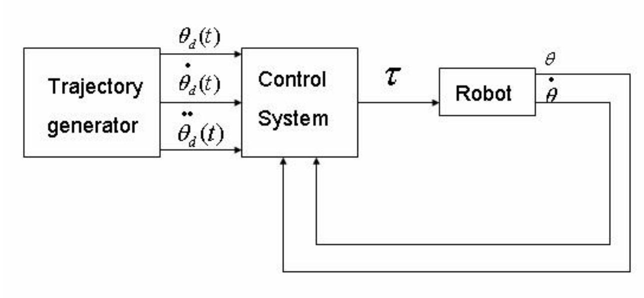

Fig. 7 High-level Block Diagram of a Robot Control System

Based on previous materials, the means to calculate joint position time histories that correspond to desired end-effector motions through space are obtained. [5]

The manipulator will be modeled as a mechanism which is instrumented with sensors at each joint to measure the joint angle, and an actuator at each joint to apply a torque on the neighboring link. Since the manipulator joints have to follow prescribed position trajectories, but the actuators are commanded in terms of torque, some kind of control system must be used to compute appropriate actuator commands which will realize this desired motion. Normally, these torques are computed by using feedback from the joint sensors to compute the torque required.

Fig. 7 shows the relationship between the trajectory generator and the physical robot. The robot accepts a vector of joint torques, τ , from the control system. The manipulator's sensors allow the controller to read the vector of joint positions, θ , and joint velocities, $\dot{\theta}$.

All signal lines in Fig. 7 carry N x 1 vectors [6] (where N is the number of joints in the manipulator).

III. Experimental Work

A. Simulation

It provides a flexible MATLAB interface to virtual reality worlds. After creating MATLAB objects and associating them with a virtual world, the virtual world can be controlled by using functions and methods.

From MATLAB, the user can set the positions and properties of VRML objects, create callbacks from graphical user interfaces (GUIs), and map data to virtual objects.

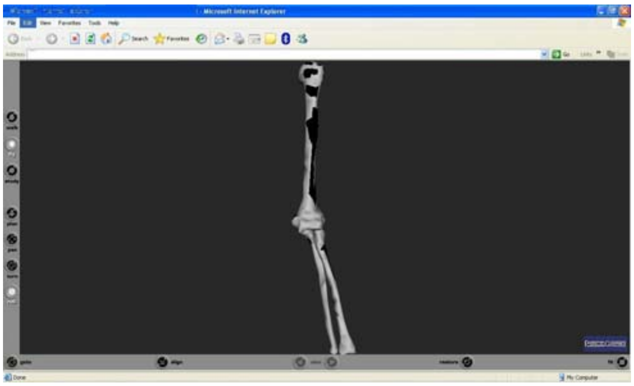

Fig.8 The bones a human upper arm in a VRML Viewer.

The user can also view the world with a VRML (Virtual Reality Markup Language) viewer, determine its structure, and assign new values to all available nodes and their fields. A simulation of the human arm motion will then be shown in the next figure.

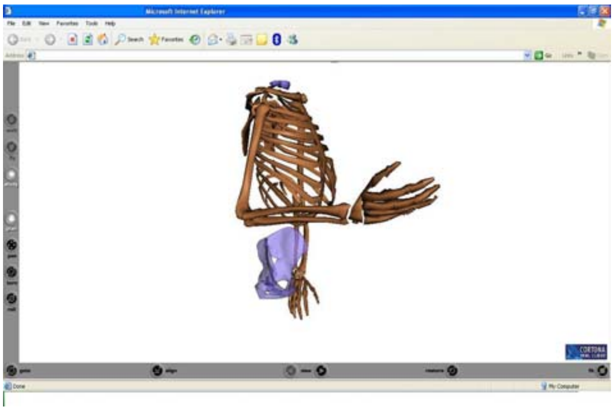

Fig.9 Human Upper Arm in a VRML Viewer.

The Virtual Reality Toolbox includes functions for retrieving and changing the virtual world properties and for saving the VRML files corresponding to the actual structure of a virtual world. MATLAB provides communication for control and manipulation of virtual reality objects using MATLAB objects.

IV. CONCLUSION

This paper presents the mechanical analysis of human upper arm joints (shoulder, elbow, wrist and fingers). The research is then extended to the study of human manipulator.

Kinematics is the science of motion. In human movement, it is the study of the positions, angles, velocities, and accelerations of body segments and joints during motion. The body segments are considered to be rigid bodies for the purposes of describing the motion of the body.

Forward kinematics is to compute the position and orientation of finger tip (end-effector) by using given a set of joint angles. The position and orientation computed is relative to the arm (base frame). The simulation of human arm forward kinematics is performed through MATLAB Graphical User Interface and VRML.

Inverse kinematics does the reverse of forward kinematics. It is used to compute all possible sets of joint angles by using given position and orientation of the finger tip. The simulation of human arm inverse kinematics is performed through MATLAB Graphical User Interface and VRML.

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