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Research Article

Amaranthine: Humanoid Robot Kinematics

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ABSTRACT

***H**umanoid robots are utilized in a wide scope of fields to repeat human activities. This paper presents the component, arrangement, numerical demonstrating, and workspace of a 3D printed humanoid robot - Amaranthine. It additionally examines the likely extent of humanoid robots in the current day and future. Robots can be modified for robotization according to the interest of the undertaking or activities to be performed. Humanoid robots, while being one of the little gatherings of administration robots in the current market, have the best potential to turn into the modern device of things to come. Presenting a Humanoid Robot-like Amaranthine holds gigantic degree significantly in the fields of clinical help, showing help, enormous businesses where uncompromising activities require application-explicit programming, and so on Amaranthine was 3D printed and collected at the RISC Lab of University of Bridgeport.*

Keywords: *MyRobotLab, Denavit-Hartenberg, Arduino, MATLAB, Humanoid Robot, Forward Kinematics, OpenCV*

1. INTRODUCTION

Humanoid robots are the most arising and testing research field in Robotics. As time passes, robots are moving out from production line floors and entering our homes aiding our day by day lives. Humanoid robots are utilized in a wide scope of fields to duplicate activities and help people. To fabricate such robots at an enormous scope will be expensive as a great deal of hardware and crude material will be required. They hold a ton of potential as far as examination. Notwithstanding the application zone, one of the basic issues handled in humanoid advanced mechanics is the comprehension of human-like data preparing and the basic instruments of the human cerebrum in managing this present reality [2].

Motivated from the open-source stage INMOOV, the parts were 3D printed and collected AMARANTHINE with numerous highlights [1]. Beforehand numerous papers have been distributed dealing with different parts of INMOOV [3]. This paper centers around the component, design, numerical figuring's and workspace of the humanoid robot utilizing MATLAB.

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Amaranthine is a 3D printed robot where all the parts including head, hands, middle, back, and shoulder were gathered with various kinds of servo engines relying upon the heap for each joint. Amaranthine is controlled through voice orders utilizing Arduino Mega microcontrollers fueled by MyRobotLab. It very well may be customized for various sorts of robotization undertakings according to the interest of the tasks to be performed.

Amaranthine Robot System is a human-sized humanoid robot with a stationary pedestal, torso, 6-(dof) head with dual 5-(dof) arms, stereo vision system, tactile stimulation from a metal fingertip sensor to sense the heat sensation and point cloud data collection from Kinect placed in the torso.

The Amaranthine arm configuration has 5-dof robot arms. The 5-dof mechanical arms are named vertically expressed with 5 revolute joints. It is a truly reliable and safe mechanical framework intended for instructive reason. This framework helps in acquiring hypothetical and down to earth insight in advanced mechanics, mechanization and control frameworks.

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In the following segment outline of the Amaranthine Humanoid Robot has been examined, trailed by kinematics investigation and conditions through MATLAB including forward kinematics arrangements.

2. AMARANTHINE DESCRIPTION

Amaranthine's physical attributes are that it is about 2' tall and weighs about 8.2 kgs.

The regular pose with all zero joint angles of the Amaranthine can be seen in the Figure 1 below.

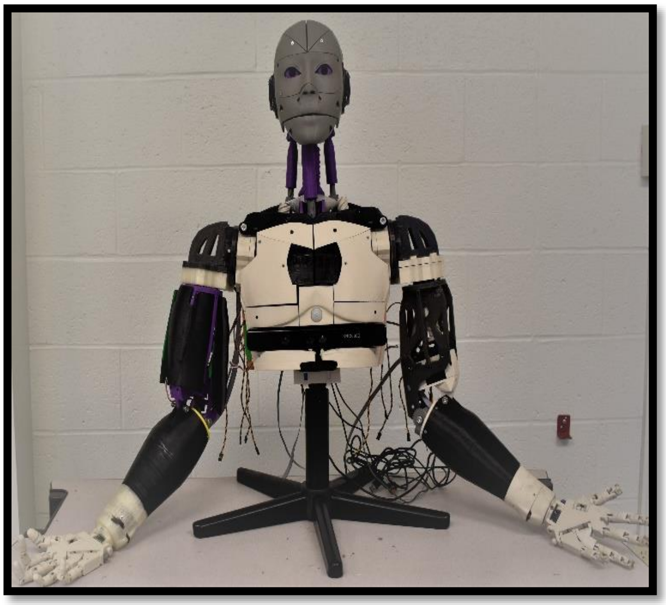

Figure 1. AMARANTHINE Humanoid Robot, Zero Pose

The zero pose is the rest position of the robot is the same as in humans which is the normal resting balance position [11].

Amaranthine build up can be divided into 5 sections as discussed further in this paper.

2.1. Amaranthine Hardware Mechanism

Amaranthine parts have been 3D printed in the RISC Lab of University of Bridgeport with MakerBot Replicators. The filament used for printing the parts is Polylactic Acid and Acrylonitrile Butadiene Styrene commonly known as PLA and ABS respectively in the industry. All the parts of the robot from gears, eyes to big chest covers have been 3D printed. Multiple printers were used to print these parts so that the process of assembling can be done faster. The gears have been printed with 30% infill with 3 shells so that these parts are strong enough to handle the load of the servo motors and its movements while the chest and head covers are printed with 15% infills and 2 shells so that the weight of the robot is not much. Figure 2. shows 3D printed parts before assembling of hand with servo motors.

Figure 2. 3D printed parts of Hand before assembling

The Amaranthine arm has 5 high torque servo motors which are responsible for its actuation to move the arms around as per the programmed commands. This makes a normally agreeable arm that would be upheld in its workspace when speaking with items and people. Every 5-dof arm has a pinnacle force of 2.5 Nm for the initial four dynamic joints (the shoulder and the elbow), while the wrist joint has a pinnacle force of 1.07 Nm. Which is a sufficient measure of power to lift loads as much as five pounds.

Fingers of the robot comprises of 16-dof. Each finger is attached to the metal strip to sense the heat of an object and due to this sensor, it can analyze the pressure required by it to hold an object

The head of Amaranthine comprises of 5 servo motors which control the movement of neck, eyes and jaw. The eyes are fixed with HD cameras which can record and click pictures or movements as per the instructions given to Amaranthine. Ears are fixed with 10 Watts speakers for audio.

The torso is not in motion but withholds an important part in the whole set up. It holds all the nervo boards connecting all the servo motors, camera and speakers. It also holds Kinect XBOX-360 which is placed below the chest. It works on 3 vital points video camera, depth sensor and a multi-array microphone. Here, Kinect is being used to capture human gestures and replicate those actions by Amaranthine. Through Kinect it sees and understands the world around and captures in 3D view. Torso also has a PIR motion sensor to sense the motion of a human being around the robot and do certain actions.

2.2. Amaranthine Configurations

Each part in the humanoid robot has different configurations and set up.

The servo motors in the head configuration are responsible for the jaw movement when Amaranthine converses with the user. Eye movements are managed by 2 small servo motors and the

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head tilt/pan are managed my 3 servo motors attached to neck. Each servo motors have been calibrated using Arduino for specific angle movement. The eye camera is connected to a computer screen where the real time video and pictures are captured via OpenCV.

The high force servo engines utilized in both the arms have been reproduced by eliminating the potentiometer from these engines which control the level of development. The potentiometers eliminated from these engines are being utilized independently from the external side to control these engines. potentiometers assume a significant part in charge of these engines, they are being utilized as a different element so the servo development of the hand can be run for more extensive reaches.

The objective of this paper is to study the forward kinematics of Amaranthine. There is neither a spherical shoulder nor a spherical wrist in this robot of 5-dof arms (i.e. 3 successive coordinate frames are meeting at the same origin). A 3-dof shoulder, a 1-dof elbow, and a 1-dof wrist were considered for designing this robot. Both 5-dof arms incorporate point position and joint force detecting. Each arm has five servo engines in the front arm to control the activities of the fingers and thumb. Each bicep is outfitted with two servo engines to control the lower arm and bicep development.

The fingers are also controlled by 5 servo motors placed in the forearm connected through ribbon cables and fishing lines as clearly seen in Figure 3. The ribbon cables are attached to Arduinos for the command control and power supply. Temperature sensors on each finger-tips to sense the heat of the substance/human fingers or body along with silicone grippers to hold objects firmly.

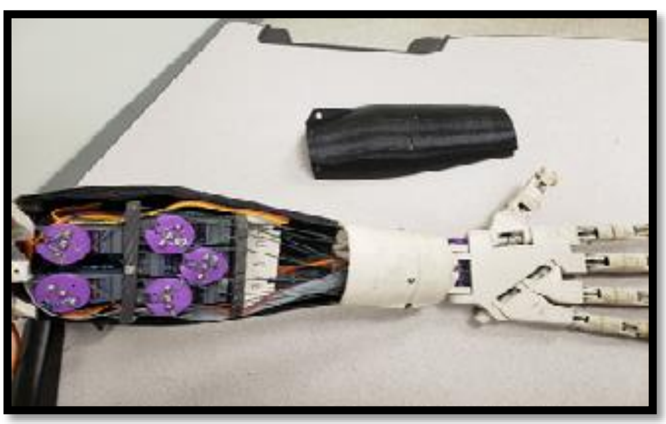

Figure 3. Servo motors controlling finger movement

Kinect is not connected to Arduino board but to a computer screen via a USB cable to see the 3D view of the surrounding. It captures motion data of the surroundings which can be used to study in different motion states and replicate actions.

The robot comprises of Nervo Board Shield (Printed Circuit Boards) for the associations made in the head and middle, worked with two ARDUINO MEGA 2560s. The ARDUINO MEGA fixed in the correct arm controls a large portion of the robot developments while the other MEGA controls the left arm. The camera has a most extreme goal of 720p HD video which can be utilized to perceive faces and save information. Amaranthine can be associated with 3 screens to envision and catch information from the camera, Kinect and the temperature and PIR sensors.

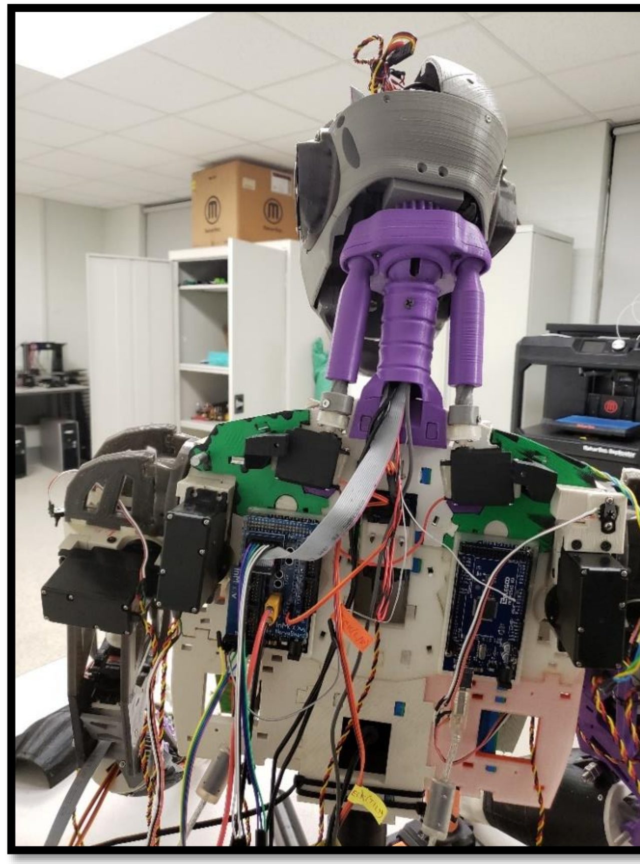

Figure 6. Nervo Boards for the head and both arm movements

2.3. Amaranthine Software

The Amaranthine Robot is programmed and controlled through MyRobotLab, an open-source GUI Java service based framework which is generally used for robotics and creative machine control. It runs on the Java update 8u141 and offers services like machine vision JavaCV/OpenCV, speech recognition from Sphinx 4, text to speech from FreeTTS, motor control, servo control, GUI control and microcontroller communication. It basically uses Arduino microcontrollers serial communications and turns Arduino into a I/O-slave [5].

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3. MATHEMATICAL MODEL OF AMARANTHINE ROBOT: DENAVIT-HARTENBERG (DH) PARAMETERS

The Denavit-Hartenberg (DH, Denavit and Hartenberg, parameters are presented in this section, for each of the arms (two 5-dof arms) for the Amaranthine Robot. The Denavit-Hartenberg (DH) Parameters are the four parameters associated with a convention for attaching reference frames to the links of spatial kinematic chain or robotic manipulator.

Using the basic conventions of the Denavit-Hartenberg principle, the DH tables for the Right and Left arms of Amaranthine were calculated. The link lengths and joint offset length was calculated using Kinect gives the picture of the object in skeleton form. It shows the image in X-Y-Z dimension with the link measurements

Joint Number	Joint Type	Link Length (a)	Twist Angle (α)	Joint Offset length (d)	Joint Angle (θ)
1	Revolute	152.4	-90 deg	39.4	θ_{R1}
2	Revolute	180.6	-90 deg	0	θ_{R2}
3	Revolute	282.6	90 deg	28.4	θ_{R3}
4	Revolute	266.7	-90 deg	12.7	θ_{R4}
5	Revolute	228.6	0 deg	0	θ_{R5}

Table 1. DH table of 5-dof Right Arm

Joint Number	Joint Type	Link Length (a)	Twist Angle (α)	Joint Offset length (d)	Joint Angle (θ)
1	Revolute	152.4	90 deg	39.4	θ_{L1}
2	Revolute	180.6	90 deg	0	θ_{L2}
3	Revolute	282.6	-90 deg	28.4	θ_{L3}
4	Revolute	266.7	90 deg	12.7	θ_{L4}
5	Revolute	228.6	0 deg	0	θ_{L5}

Table 2. DH table of 5-dof Left Arm

Using these DH table of the arms, the forward kinematic equations were calculated and workspace of the both the arms followed by the path trajectory simulations to observe the position, velocity and acceleration of each [8].

4. AMARANTHINE FORWARD KINEMATICS

In Forward Pose Kinematic Analysis, the position of the end-effector (X, Y, Z) for a specific pose is calculated using the available link lengths (a) and joint displacements (θ,d) respective to the pose. On substituting the D-H parameters for each individual joint, different matrices are obtained. Multiplying all the five matrices for each joints, a link transformation matrix (4 x 4 matrix) is attained. The first three elements in the last column of this matrix give the (X, Y, Z) coordinates that define the position of the end-effector, here being the fingers.

The equations obtained for each co-ordinate point for the amaranthine arm after calculation are:

$$\begin{aligned} X = (a_5c_5)(c_1c_2c_3c_4 + s_1s_3c_4 - s_2s_4c_1) \\ + (a_5s_5)(-c_1c_2s_3 + s_1c_3) \\ + (a_4c_4)(c_1c_2c_3 + s_1s_3) - (c_1s_2)(a_4s_4) \\ + (c_1c_2s_3 - c_3s_1)(d_4) + c_1c_2a_3c_3 \\ + s_1s_3a_3 - c_1s_2d_3 + a_2c_1c_2 + a_1c_1 \end{aligned}$$

$$\begin{aligned} Y = (a_5c_5)(c_4s_1c_2c_3 - c_1s_3c_4 - s_1s_2s_4) \\ + (a_5s_5)(-s_1c_2s_3 + c_1c_3) \\ + (a_4c_4)(s_1c_2c_3 - c_1s_3) - (s_1s_2)(a_4s_4) \\ + (s_1c_2s_3 - c_1c_3)(d_4) + s_1c_2a_3c_3 - c_1a_3s_2 \\ - s_1s_2d_3 + a_2c_2s_1 + a_1s_1 \end{aligned}$$

$$\begin{aligned} Z = (a_5c_5)(-s_2c_3c_4 - c_2s_4) + (a_5s_5)(s_2s_3) + (a_4c_4)(-s_1c_3) \\ - c_2(a_4s_4) - s_2s_3d_4 - s_2a_3c_3 - c_2d_3 \\ - a_2s_2 + d_1 \end{aligned}$$

This is a generalized equation obtained. Substituting specific values for the Joint angle (θ) in the above equations, the coordinates for the position of the end-effector can be calculated [10], [12], [14].

5. WORKSPACE AND PATH TRAJECTORY SIMULATIONS OF AMARANTHINE'S ARMS

The 'Workspace of the Manipulator' can be defined as "the set of points that can be reached by its end-effector." In the previous section it stated the theoretical calculation of forward kinematic equations for both the arms of Amaranthine, now, the simulated the workspace of both the arms in MATLAB using Robotics Toolbox was derived. The maximum and minimum workspace limits for the functioning of the arms were set, like human arm movement limits.

'Path Planning' can be defined as "generating a feasible path from a start point to a goal point. It usually consists of a set of connected points", while 'Trajectory Planning' is defined as "generating a time schedule for how to follow a path given constraints such as position, velocity and acceleration." Here, after running the simulation of Trajectory Planning of Right and Left arms, the DH table mathematical model created is verified.

This can be further understood and explained in the below table 3:

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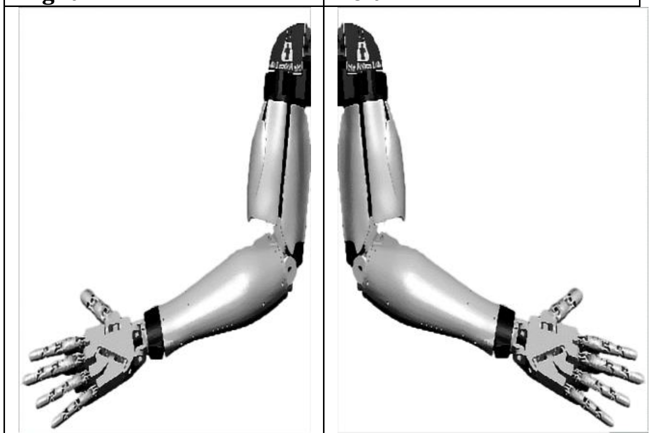
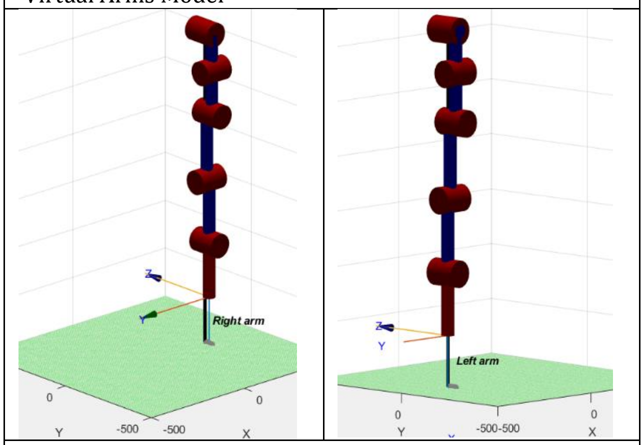
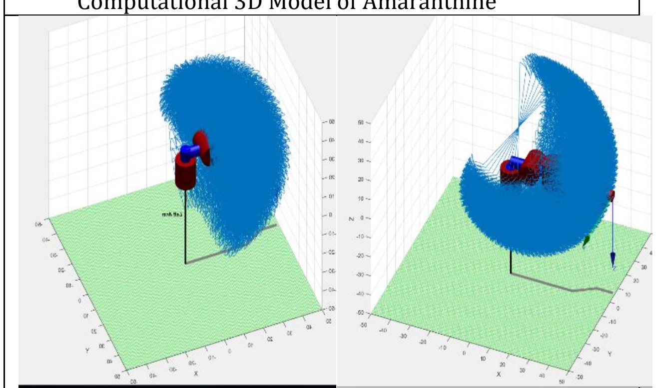
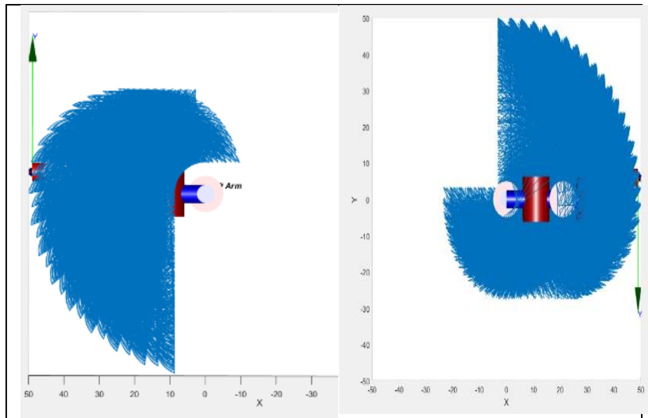
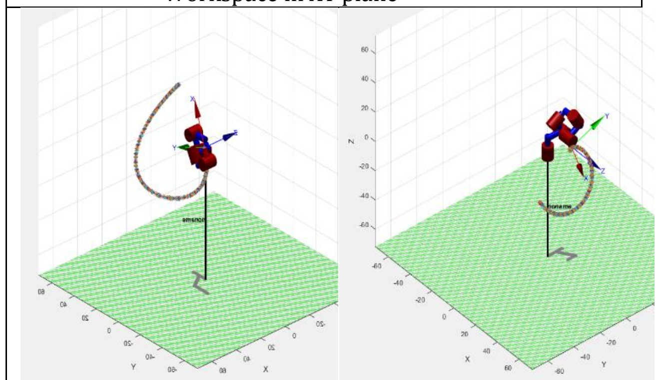
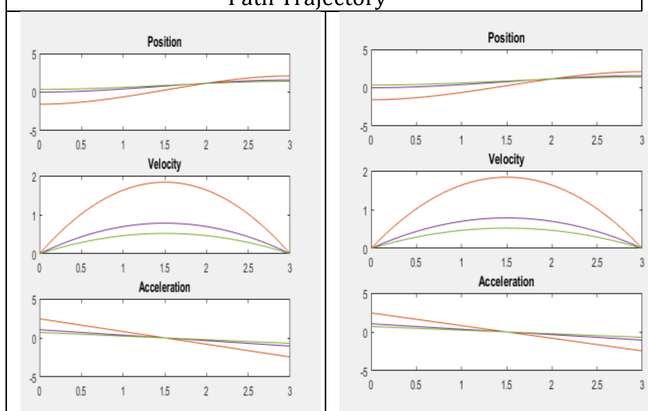
Table 3. Computational comparison between the Right and Left Arm

Right Arm	**Left Arm**
	
Virtual Arms Model	
	
Computational 3D Model of Amaranthine	
	
MATLAB 3D Simulation	
	
Workspace in XY plane	
	
Path Trajectory	
	
Position, Velocity and Acceleration	

From the 3 table represents the comparison study of Right and Left Arms. The First figure is the Virtual model of arms of the Amaranthine Robot and in the second figure it's the 3D computational model where each revolute joint is presented with its rotational axis. and simulations of workspace for both the arms. It is followed by MATLAB simulation images of the arms in 3D view as well as in the XY plane.

From the simulations it is inferred that the blue color portion marked in the simulation results is identified as the area of the workspace in which the robot arm can move with the major influence on the dimensions of workspace is exerted by the dimensions of links of the robots and the mechanical limitations of the joints. Thus, looking at the whole workspace

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of both the arms created together, the geometrical structure of the workspace turns out to be a sphere.

Infering from 5dof manipulator's workspace, it gives the possibility of mechanism optimization and the interaction process optimization.

The last two figures in the table are the plotting of the path trajectories of both the Right and Left arms with the calculation of their position, velocity and acceleration of each. These path trajectories trace the path by the end-effector of the manipulator to access a specific point.

6. CONCLUSION

This paper has introduced a definite kinematic examination for the two 5-dof Amaranthine (INMOOV) Humanoid Robot arms. The Denavit-Hartenberg Parameters for every sequential chain, exact length boundaries, and joint point limits were given. The 5-dof forward kinematics arrangements were created, with scientific outcomes. It is seen that the workspaces for the two arms are the identical representations of one and another. The way and direction for both the arms were plotted in MATLAB and was seen that they were additionally identical representations of each and other and then again the position, speed and quickening diagrams were the equivalent for both the arms.

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