Modeling and Simulation of a Moving Robotic Arm Mounted on Wheelchair

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***Abstract*—Wheelchairs equipped with fixed positioned robotic arms is proposed to help paralyzed people. However, such a configuration makes it hard for the users to orient the wheel chair such that the task in need lies within the arm workspace. In this work a robotic arm that slides over a track mounted over a wheelchair is proposed to attain much wider workspace, at no extra complexity of arm design. Proposed design also reliefs the need to orient the wheelchair for extra user comfort. This work represents the Kinematic equations, Dh-parameters and dynamic modeling & simulation of an RRR robotic arm moving along a path built onto a wheelchair including the 3D workspace of the system. Preliminary results show robotic arm can achieve a very dexterous workspace at no extra cost in terms of arm torques yet offering a great comfort for wheelchair users.**

Keywords—Robotic arm mounted wheelchair; Dynamic Model; Simulation.

I. INTRODUCTION

A wheelchair mounted robotic arm can help facilitating many daily activities of paralyzed people. Therefore, there is an active ongoing research line that is investigating better designs and ideas towards this goal. Many designs proposed in literature encompass poor robotic arm design. For instance, using the 6 Dof MANUS arm for the WMRA which is large in size and weight (can weigh up to 12.5 kg [1], [2]) and as each motor on the end of each joint making the weight distribution less stable maybe even tilting the wheelchair itself [5], [7].

In addition, the workspace of literature proposed designs is limited and hard to use [4], [6], [8]. This is mainly attributed to the use of fixed arm place over the wheelchair (usually on one side of the wheelchair) [3]. The latter makes it a must for the user to orient the wheelchair in order to get or use objects around the chair.

This work proposes a novel robotic arm equipped wheelchair. The design simply lets a simple light weight 3R robotic arm slide over a path that is already attached to into a wheelchair. The RRR arm motors are placed new the arm base for more stable and smooth motion. Figure 1shows the model explained in this paper showing the arm and path used on the wheelchair.

Proposed design is expected to overcome all previously proposed designs in terms of simplicity and size of reachable workspace. The arm moving around the wheelchair gives bigger workspace to the system yet makes it easier to use by wheelchair users but in order to achieve this we must carefully study the kinematics, dynamic model, relative movements and full workspace in which it operates.

Figure 1: Wheelchair mounted robot arm along path.

II. ROBOTIC ARM

As mentioned earlier the robot arm chosen for this paper will be the industrial uArm (Rotation-Rotation-Rotation arm).
An RRR robot arm has some of the best qualities amongst the robot arms; it’s very easy to control having only 3 angles yet giving a larger workspace, adding to that the low weight of arm itself, and more importantly having the motors controlling the 3 angles on the base of the arm, as you can see in Figure 2.

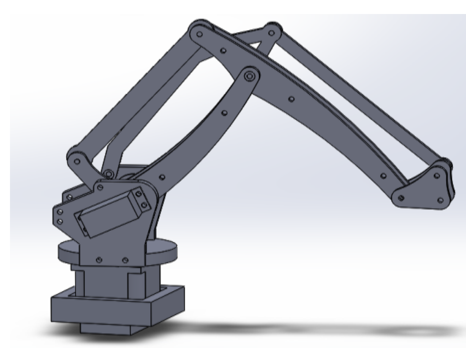

Figure 2: uArm experimental setup.

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A. Kinemetic Model

According to the well-known Denavits-Hartenberg's (DH) notation we establish the DH-parameters for the ARM by forming the reference coordination system for our robot arm as shown in figure.3.

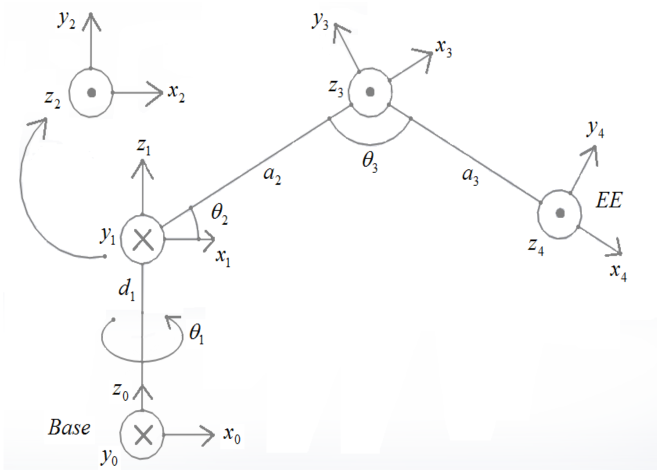

Figure 3: Reference coordination system for robot arm.

Therefore the DH parameters can be summed in table 1.

Table 1: DH parameters of the robot arm.

	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	d_1	θ_1
2	90	0	0	θ_2
3	0	a_2	0	θ_3
4	0	a_3	0	0

Starting with the **Forward Kinematics** we get the transformation matrix for the End Effecter (EE) with respect to the Base (B) of the arm:

$$^{B}T_{EE} = \begin{bmatrix} c_1c_{23} & -c_1s_{23} & s_1 & a_2c_1c_2 + a_3c_1c_{23} \\ s_1c_{23} & -s_1s_{23} & -c_1 & a_2s_1c_2 + a_3s_1c_{23} \\ s_{23} & c_{23} & 0 & a_2s_2 + a_3s_{23} + d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

As for the path, in this paper we will take the first part of the path (Y-direction) and use it for simulation so we get the path transformation matrix:

$$^{0}T_{B} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & y_B \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

Getting the full transformation matrix for the robotic arm along the path in Y-direction as:

$$^{0}T_{EE} = \begin{bmatrix} c_1c_{23} & -c_1s_{23} & s_1 & a_2c_1c_2 + a_3c_1c_{23} \\ s_1c_{23} & -s_1s_{23} & -c_1 & a_2s_1c_2 + a_3s_1c_{23} + y_B \\ s_{23} & c_{23} & 0 & a_2s_2 + a_3s_{23} + d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

Solving the **Inverse Kinematics** to get the 3 angles controlling the arm (θ_1, θ_2, θ_3) we need the End Effecter position (X, Y, Z & base offset on the path y) as shown in equations (4-6)

$$X = c_1(a_2c_2 + a_3c_{23}) \quad (4)$$

$$Y = s_1(a_2c_2 + a_3c_{23}) + y_B \quad (5)$$

$$Z = a_2s_2 + a_3s_{23} + d_1 \quad (6)$$

$$c_3 = \frac{X^2 + (Y - y_B)^2 + (Z - d_1)^2 - a_2^2 - a_3^2}{2a_2a_3} \quad (7)$$

$$s_3 = \sqrt{1 - c_3^2} \quad (8)$$

$$\theta_3 = ATan2(s_3, c_3) \quad (9)$$

$$X^2 + (Y - y_B)^2 = (a_2c_2 + a_3c_{23})^2 \quad (10)$$

$$\sqrt{X^2 + (Y - y_B)^2} = a_2c_2 + a_3c_{23} \quad (11)$$

$$c_2 = \frac{\sqrt{X^2 + (Y - y_B)^2}(a_2 + a_3c_3) + (Z - d_1)a_3s_3}{a_2^2 + a_3^2 + 2a_2a_3c_3} \quad (12)$$

$$s_2 = \frac{(Z - d_1)(a_2 + a_3c_3) + \sqrt{X^2 + (Y - y_B)^2}(a_3s_3)}{a_2^2 + a_3^2 + 2a_2a_3c_3} \quad (13)$$

$$\theta_2 = ATan2(s_2, c_2) \quad (14)$$

$$\theta_1 = ATan2((Y - y_B), X) \quad (15)$$

Using Eq. (7-15) we calculated each of the 3 angles (θ_1, θ_2, θ_3) from the X, Y, Z position of the End-Effecter.

B. Path planning

In making a single smooth motion at least 4 constraints on $\theta(t)$ are needed, as shown in equations 16 and 17 two constraints on the functions value come from the selection of initial and final values.

$$\theta(0) = \theta_0 \quad (16)$$

$$\theta(t_f) = \theta_f \quad (17)$$

An additional two constraints are that the function be continuous in velocity, which in this case means that the initial and final velocity is zero as shown in equations 18 and 19.

$$\dot{\theta}(0) = 0 \quad (18)$$

$$\dot{\theta}(t_f) = 0 \quad (19)$$

These four constraints can be satisfied by a polynomial of at least third degree.

In equation 34, a cubic polynomial has four coefficients, so it will be used to plan the path of each angle)

$$\theta(t) = b_0 + b_1 t + b_2 t^2 + b_3 t^3 \quad (20)$$

$$\dot{\theta}(t) = b_1 + 2b_2 t + 3b_3 t^2 \quad (21)$$

$$\ddot{\theta}(t) = 2b_2 + 6b_3 t \quad (22)$$

Now using the 4 constraint given in equations 16 - 19 to get the four coefficients (b_0, b_1, b_2, b_3) as shown in equations 23 - 26.

$$b_0 = \theta_0 \quad (23)$$

$$b_1 = 0 \quad (24)$$

$$b_2 = \frac{3}{t_f^2}\left(\theta_f - \theta_0\right) \quad (25)$$

$$b_3 = -\frac{2}{t_f^3}\left(\theta_f - \theta_0\right) \quad (26)$$

Giving us a polynomial of the third degree for each angle (θ_1, θ_2, θ_3), as shown in equation 20.

C. Dynamic Model

For our model we will use the Lagrangian dynamic formulation, starting by developing the expression for the kinetic energy And potential energy at the center point of each joint as:

$$k_i = \frac{1}{2} m_i v_{c_i}^T v_{c_i} + \frac{1}{2} {}^i\omega_i^T \, {}^iI_{c_i} \, {}^i\omega_i \quad (27)$$

$$u_i = -m_i \, {}^0g^T \, {}^0I_{c_i} \quad (28)$$

And using them to get the Torques and Force

$$\tau_i = \frac{d}{dt}\left(\frac{\partial K}{\partial \dot{\theta}_i}\right) - \frac{\partial K}{\partial \theta_i} + \frac{\partial U}{\partial \theta_i} \quad (29)$$

$$F = \frac{d}{dt}\left(\frac{\partial K}{\partial \dot{y}_B}\right) - \frac{\partial K}{\partial y_B} + \frac{\partial U}{\partial y_B} \quad (30)$$

To get the manipulator dynamics in Cartesian Space:

$$\tau = M(\Theta)\ddot{\Theta} + V(\Theta, \dot{\Theta}) + G(\Theta)g \quad (31)$$

$$\tau = \begin{bmatrix}\tau_1 & \tau_2 & \tau_3 & F_4\end{bmatrix}^T \quad (32)$$

$$\Theta = \begin{bmatrix}\theta_1 & \theta_2 & \theta_3 & y_B\end{bmatrix}^T \quad (33)$$

$$\ddot{\Theta} = \begin{bmatrix}\ddot{\theta}_1 & \ddot{\theta}_2 & \ddot{\theta}_3 & \ddot{y}_B\end{bmatrix}^T \quad (34)$$

Using these matrices we get- in detail- the Torques generated from the movement of each motor (angle) at any time or position given each Θ, $\dot{\Theta}$ and $\ddot{\Theta}$ at that specific time step from Eq.(31).

III. SIMULATION RESULTS

The kinematics and dynamics equation where programmed along with the path planning and workspace of the system with MATLAB using the specifications of the actual uArm robot given in table 2 as follows [10]:

Table 2: specifications of the actual uArm robot .

d_1 *(cm)*	a_2 *(cm)*	a_3 *(cm)*	y_b *(cm)*	θ_1 *(degrees)*	θ_2 *(degrees)*	θ_3 *(degrees)*
10	15	16	54	0° - 180°	0° - 90°	10° - 120°

A. Workspace

Knowing the workspace and mapping it is one of the most important steps in studying a robot arm in general, in this paper we will show the workspace in several angles to get a better understanding of the arm itself in general.

Giving the workspace for the arm at $\theta_1 = 0$ the arm will move in the X & Z plane as shown in Figure 4.

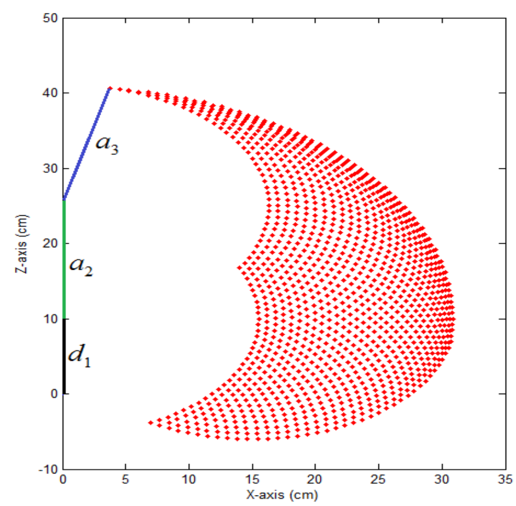

Figure 4: workspace or the arm at θ_1=0 in X-Z plane.

Now giving the workspace for the arm at $\theta_1 = 0$ along the path in Y-direction; meaning that the arm will move along the path keeping $\theta_1 = 0$.

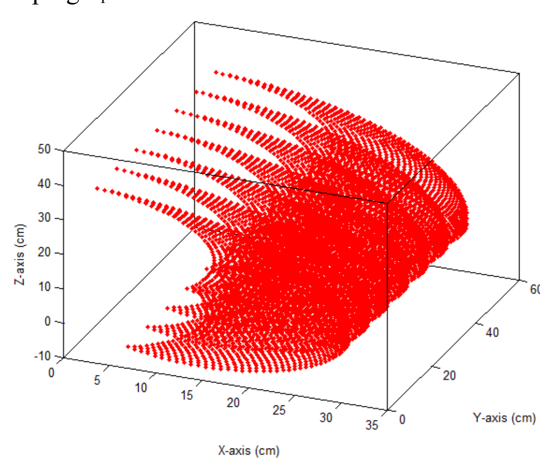

Figure 5: workspace of the arm at θ_1=0 along the path.

Now giving the workspace for the arm when θ_1 changes in the range from (0 to π) as shown:

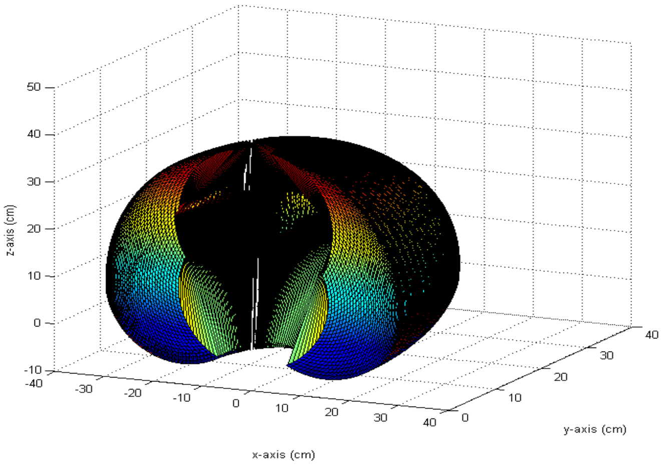

Figure 6: workspace or arm at θ_1 range from (0 to π).

B. Path of the End-Effecter (EE)

In this part we selected two different pionts for the End-Effecter, whithin the workspace (initial and final positions that contain the coordinates X, Y, Z) and check the path it will take based on the above analysis .

$$Pos_1 = [31 \quad 0 \quad 10] \tag{35}$$

$$Pos_2 = [25.1 \quad 64.5 \quad 17.5] \tag{36}$$

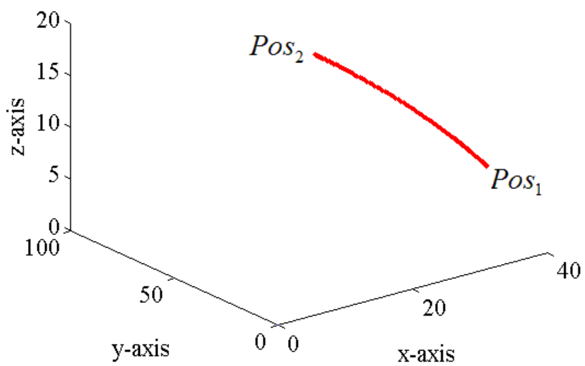

Figure 7: path of EE at given initial and final positions.

As you can see in Figure 7 the path of the End-Effecter in Cartesian space moving from the first point to the second one, and for more details Figures 8 through 10 show the projection of the path on the 3 planes(X-Y, X-Z, and Y-Z).

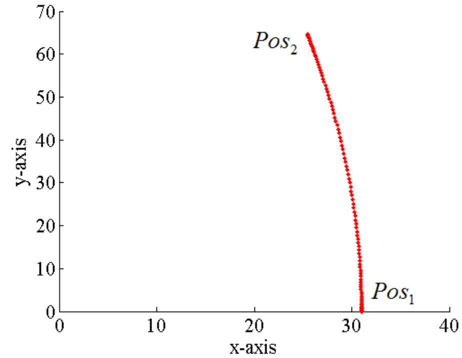

Figure 8: Projection on path on X-Y plane.

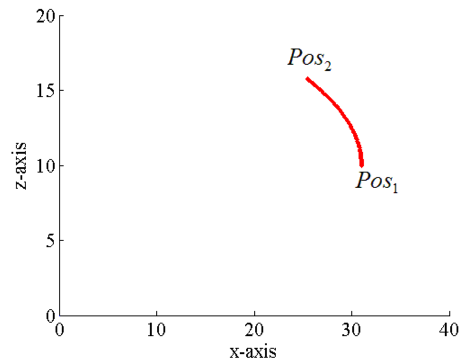

Figure 9: Projection on path on X-Z plane.

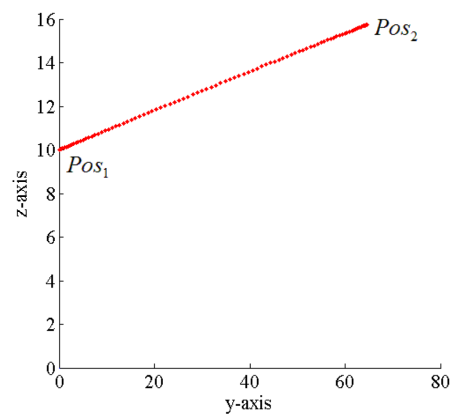

Figure 10: Projection on path on Y-Z plane.

C. Arm angles

For the path used in the previous example the 3 angles ($\theta_1, \theta_2, \theta_3$) change with time as shown in Figure 11.

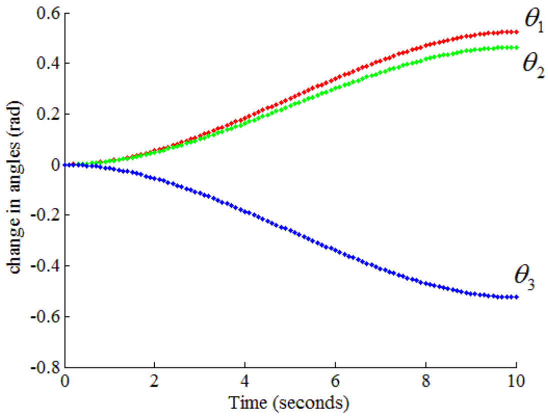

Figure 11: Change in the 3 angles with time (along the path).

D. Torques

To get the Torques of each motor (angle) we use Equation 31 and the example path we created above.

The Torques and Forces $\tau = [\tau_1 \quad \tau_2 \quad \tau_3 \quad F_4]$ will be calculated and shown in Figure 12.

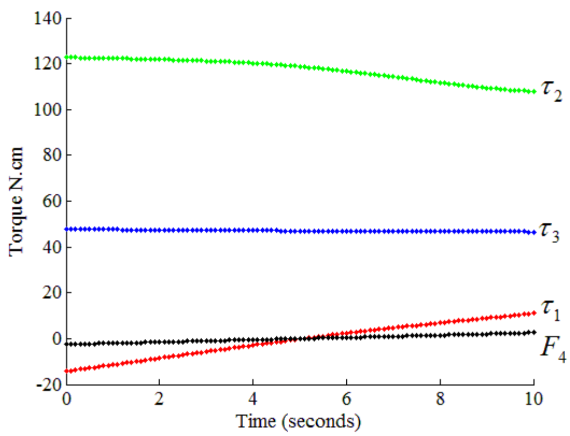

Figure 12: Change Torques with time.

IV. CONCLUSION AND FUTURE WORK

A wheelchair mounted robot arm was designed to help with the everyday activities of people with disabilities, and to exceed the capabilities of the current designs so far, adding a path for the robotic arm to move on is the perfect solution replacing the conventional fixed arm configurations, but to do so we must study all the aspects of the arm, as in this paper we must take in consideration the Kinematics and Dynamics of the system and confirm them in modeling & simulations before we can build it and test it out, which we hope to do in the near future. Also using this robot arm has a lot of different advantages from stability to accuracy while in use and will have a more variety of work in the future.

One of the ideas for future work that will be done is actually making the path along the whole edges of the wheelchair as shown in Figure 13.

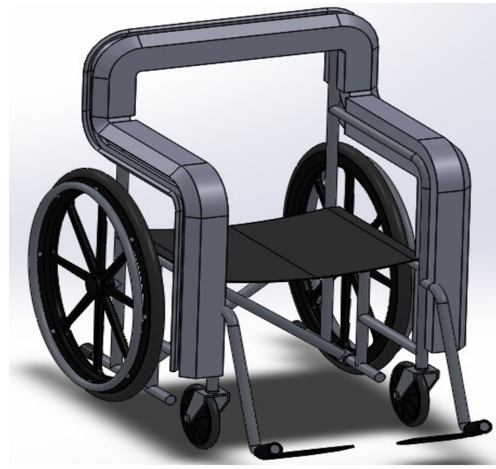

Figure 13: Future work showing path along wheelchair.

Adding a path in the Z-direction to defy gravity and slipping upwards and downwards, just imagine the possibilities this can have: such as picking up things from the ground, or maybe reaching something to the persons head or face to eat/drink, the possibilities are endless.

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