Analysis of Human Arm Motions at Assembly Work as a Basic of Designing Dual Robot Arm System

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Abstract - **An analysis of human arm motions has been studied as a preliminary result prior to the design of an artificial shoulder-attached double-arm robot to imitate human arms' motions. For modeling the dual arm robot, a DH-parameter's based forward- kinematics of the arms are analyzed. Since in the real world human hands hold various types of objects with distinct weights and volumes, we take into account unpredictably center of mass of the entire arms as uncertainty. For this purpose, the model to follow must be based on human's behavior. Therefore, human anthropomorphic is required to be applied for determining the robot's parameters. In addition, human motion limitations must be considered as the limitation of the robot's motions as well. Simulations of the results are presented to verify the performance of the model and will be used as model for adaptive controller design.**

Keywords - **Human arms motions, human anthropomorphic, artificial dual arm robot, Denavit-Hartenberg paradigm, forward kinematics.**

I. INTRODUCTION

Studies of human hands' motions at assembly works have been carried out and developed by so many researchers. Various studies are focused on motions at manual assembly works. It was concluded that human works are accomplished by two hands. Particularly, all manual works consists of relatively few fundamental repetitive motions. For instance, "picking up" and "putting down" are two of the most frequently used groups of motions. Nowadays, these studies are useful as a basis for designing artificial tools for the rehabilitation of paralyzed patients such as Harmony Exoskeleton Arms robot for arm or back injuries therapist developed by Texas University of Austin [1], etc. In order to accelerate the rehabilitation, it is necessary to build a system that mimics the human arms and their motion. Therefore, an artificial shoulder-attached double-arm robot to imitate human arms' motions is designed.

The arms are important parts of human body that always move and on top of that value investment for working tools. At manual assembly the arms motions inspires the basic system design of arms robot assembly such as those reported by Van Zutven [2], Smith et. al. [3], Adrien Dataset. et.al [4] Amar Benerji and Ravi N Banavar [5]. Human arms have few connected joints such as upper hand (link 1), forehand (link 2), and hand (link 3) which is in the humanoid robot system known as EndEffector. All the joints of arm system give possibility for arm to move or do the motion.

As typical procedures used in robotics field, a kinematics analysis using Denavit-Hartenberg (DH) paradigm is developed to model the motions of human arms. The DH parameters are obtained by Therbligh motions measurements. Therefore, the designed robot arms can represent humans' anthropometric.

The organization of this paper is described as follows. Section I discusses about the motivation of this study. Section II explains the methodology to solve the problem. In Section III, the results and discussions are presented. Finally, the conclusions and the future works are described.

II. METHODOLOGY

In order to let the arms moving as a human-like manner, the arms should have degree of freedom to, at least, perform the basic movement for manual assembly that will be designed, as shown in Fig 1. Therefore, through this paper a study of human dual-arms motions need to be performed as a basis of designing dual-arms robot.

A. Model and Motion Approaching

For the simplicity of analysis, the model of motions that were examined is applied using Therblick motions [6]. It was assumed that the Therblick motions represent the basic motions for a human activity in general. These motions, such as "reach", "move", and "release" (where in rest of this paper, the motions are represented as REACH, MOVE, and RELEASE, respectively) have been developed from simple manual assembly. Human arms

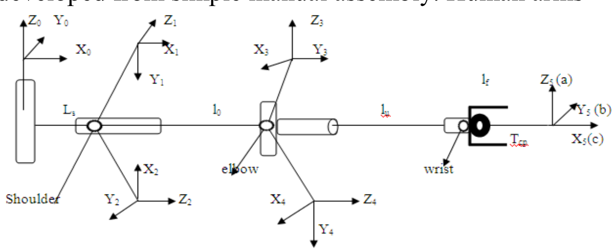


Fig 1: Kinematic model structure on the arm [2].

have 7 DOF's [7], i.e., three on the shoulder, two on the elbow, and two on the wrist. The effect of two DOF's in the wrist can be negligible. However, the wrist joint only has one DOF which gives full control over the orientation of the gripper. Each DOF has a corresponding link: The upper and lower arms both are the links to be considered. The lengths of the links are determined from the ratio between bodies segments expressed as a fraction of the total height [8]. The arms can be modeled by using Denavit-Hartenberg (D-H) approach [9]. The D-H paradigm uses 4 parameters for each link, i.e., θ_i, α_i, a_i, and d_i defined as the rotation angle about *z*-axis of the initial joint, the rotation angle about *x*-axis of the initial joint, the distance of the next joint in the direction of *x*-axis of the initial joint, and the distance of the next joint in the direction of *z*-axis of the initial joint, respectively.

The coordinate of the *i*-th joint is described by the following equation:

$$[x_i, y_i, z_i, 1]^T = A_i [x_{i-1}, y_{i-1}, z_{i-1}, 1]^T, \quad (1)$$

$$A_i = Rot_{z,\theta_i}\, Trans_{z,d_i}\, Trans_{x,a_i}, Rot_{x,\alpha_i}, \quad (2)$$

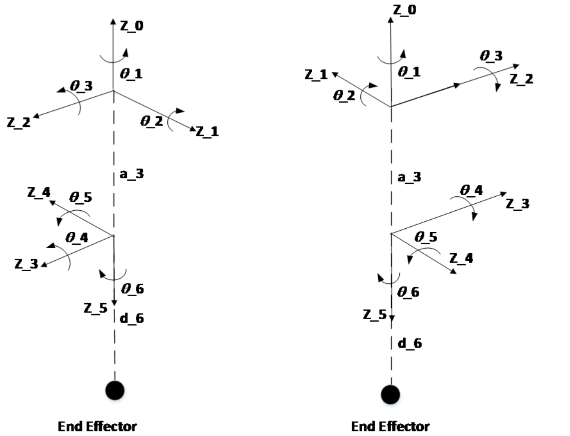
where Rot_{z,θ_i} and Rot_{x,α_i} are the matrices of rotation about z-axis by θ_i and rotation about x-axis by α_i, and are formulated as

$$Rot_{z,\theta_i} = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & 0 \\ \sin\theta_i & \cos\theta_i & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

and

$$Rot_{x,\alpha_i} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha_i & -\sin\alpha_i & 0 \\ 0 & \sin\alpha_i & \cos\alpha_i & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad (4)$$

respectively. $Trans_{z,d_i}$ and $Trans_{x,a_i}$ are the matrices of translation along *z*-axis by d_i and translation along x-axis



(a) (b)

Fig 2: The model of two arms robots. (a) right arm and (b) left arm.

by a_i and are formulated as

$$Trans_{z,d_i} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

and

$$Trans_{x,a_i} = \begin{bmatrix} 1 & 0 & 0 & a_i \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad (6)$$

respectively. The parameters θ_i, a_i, d_i, and α_i are called "D-H parameters" and are defined as the *i*-th link's angle, length, offset, and twist, respectively (see Table I). By this design, we conclude that the following basic motions can be connected to the D-H mechanism:

1) Vertical flexion is represented by θ_2,
2) Horizontal flexion is represented by θ_4,
3) Horizontal extension is represented by θ_3.

III. RESULTS AND DISCUSSIONS

By applying the D-H model, the REACH motion can be achieved by combining vertical flexion and horizontal flexion. Therefore, the involving joints are θ_2 and θ_4. In addition, the MOVE motion can be achieved by combining horizontal flexion and horizontal extension. In other words, θ_4 and θ_3 contribute to this type of motion. The last motion is RELEASE, i.e., the motion of releasing object after being executed. Here, θ_4 is rotated.

TABLE I
D-H Parameters

Left Arm				
Link	α (rad)	*a*(cm)	*θ* (rad)	*d*(cm)
1	-π/2	0	*θ*1	0
2	π/2	0	π/2 + *θ*2	0
3	0	28	*θ*3	*d*3
4	π/2	0	*θ*4	0
5	−π/2	0	−π/2 + *θ*5	*d*5
6	0	0	*θ*6	33
Right Arm				
Link	α (rad)	*a*(cm)	*θ* (rad)	*d*(cm)
1	π/2	0	*θ*1	0
2	π/2	0	−π/2 + *θ*2	0
3	0	28	*θ*3	0
4	π/2	0	*θ*4	0
5	π/2	0	π/2 +*θ*5	*d*5
6	0	0	*θ*6	33

TABLE II: CHARACTERISTICS OF THERBLIGH MOTIONS

No	Left						Therbligh	Right					
	L1			L2				L1			L2		
	Motion	Angle (°)	Time(s)	Motion	Angle (°)	Time(s)		Motion	Angle (°)	Time(s)	Motion	Angle (°)	Time(s)
1	Vertical Flexion	45	1	-	-	-	REACH	Vertical Flexion	45	1	-	-	-
2	-	-	-	Horizontal Flexion	35	0.9		-	-	-	Horizontal Flexion	35	0.9
	-	-	-	Pronasi	90	0.9		-	-	-	Pronasi	90	0.9
No	Right Arm						Therbligh	Left Arm					
	L1			L2				L1			L2		
	Motion	Angle (°)	Time(s)	Motion	Angle (°)	Time(s)		Motion	Angle (°)	Time(s)	Motion	Angle (°)	Time(s)
1	Horizontal Extension	50	0.7	Horizontal Flexsion	55	0.7	MOVE	Horizontal Extension	50	0.7	Horizontal Flexsion	55	0.7
No	Right Arm						Therbligh	Left Arm					
	L1			L2				L1			L2		
	Movement	Angle (°)	Time(s)	Movement	Angle (°)	Time(s)		Movement	Angle (°)	Time(s)	Movement	Angle (°)	Time(s)
1	-	-	-	Horizontal Ekstension	10	0.9	RELEASE	-	-	-	Horizontal Ekstension	10	0.9

For obtaining actual values of vertical flexion, horizontal flexion, and horizontal extension for each motion, a measurement applied to two volunteers was done. According to the measurements, we obtain results for actual Therbligh REACH, MOVE, and RELEASE that are shown in Table II. Note that the motion simulated uses an assumption of constant average angular velocities of all joints. Note that the measurements of actual human anthropometry were performed by using manual manner. Therefore, the results are not highly accurate. However, to handle this problem, we measure the accomplishment time in Table II. It makes sense that the accomplishment time is the result of human muscles' efforts to compensate the gravitational effect causing by the ma1ss of the arms.

A. Therbligh Test 1: Reach

The results of simulation of REACH motion is shown in Fig. 3, and the progression of the end-effectors of left and right arms are revealed in Fig. 6 and Fig. 7.

B. Therbligh Test 2: MOVE

The results of simulation of MOVE motion is shown in Fig. 4, and the progression of the end-effectors of left and right arms are revealed in Fig. 8 and Fig. 9.

C. Therbligh Test 3: RELEASE

The results of simulation of RELEASE motion is shown in Fig. 5, and the progression of the end-effectors of left and right arms are revealed in Fig. 10 and Fig. 11.
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From the simulation, it can be concluded that the REACH motion depends on the 2nd and 4th joint, the MOVE motion depends on the 3rd and 4th joint, and the RELEASE depends on the 4th joint. The results will be considered for the next step of the research, i.e., the design of adaptive control and the involvement of the weight of human arms and motors instead of Link 1 and Link 2.

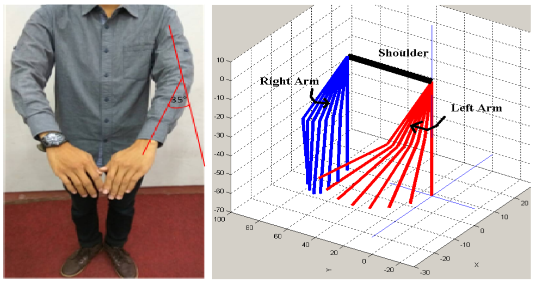

Fig. 3. REACH configuration.

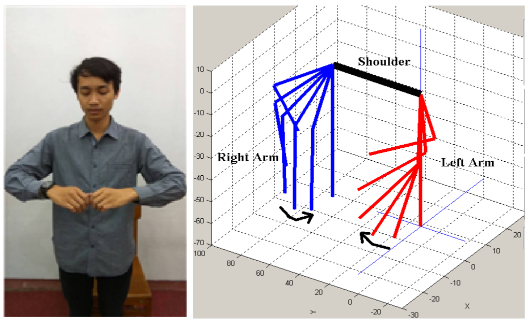

Fig. 4. MOVE configuration.

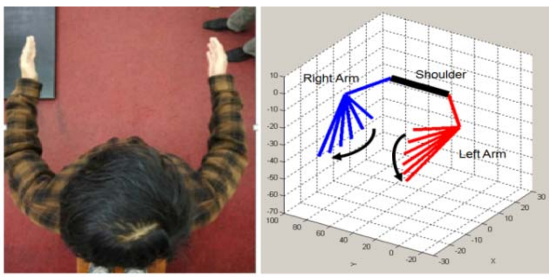

Fig. 5. RELEASE configuration

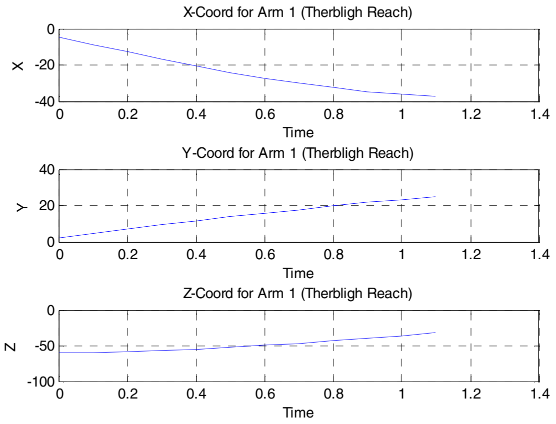

Fig. 6. Progressions of the REACH motion of left end-effector projected to X, Y, and Z coordinates.

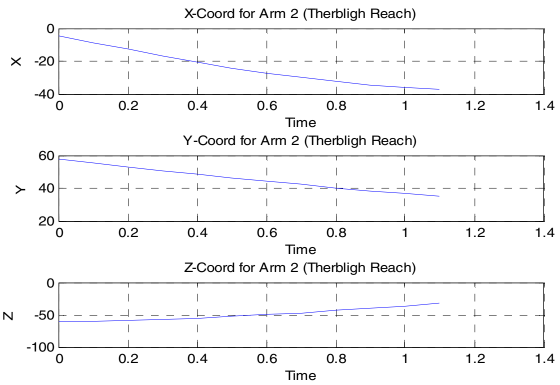

Fig. 7. Progressions of the REACH motion of right end-effector projected to X, Y, and Z coordinate.

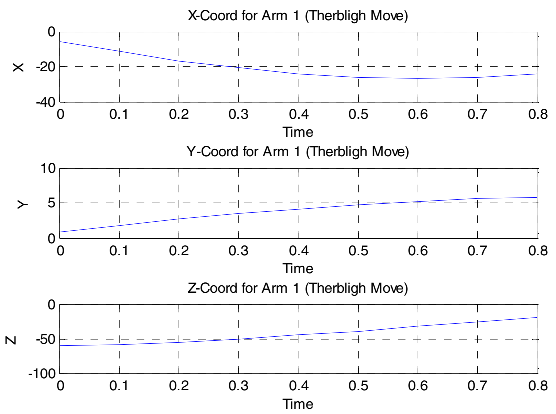

Fig. 8. Progressions of the MOVE motion of left end-effector projected to X, Y, and Z coordinates.

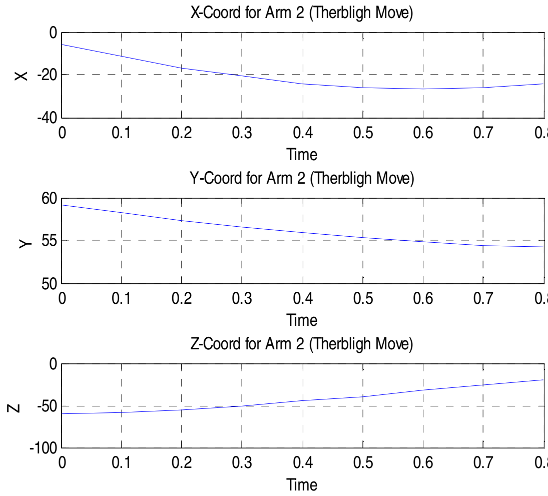

Fig. 9. Progressions of the MOVE motion of right end-effector projected to X, Y, and Z coordinate.

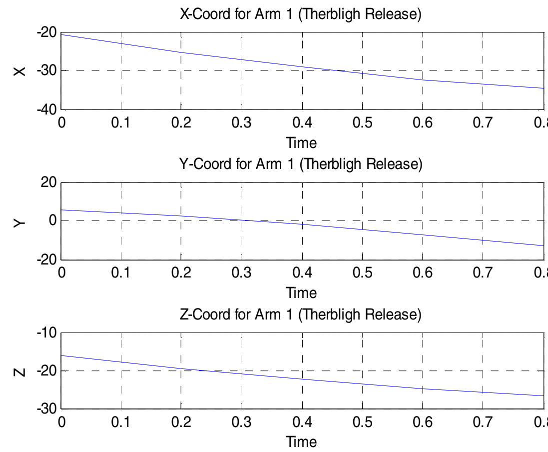

Fig. 10. Progressions of the RELEASE motion of left end-effector projected to X, Y, and Z coordinate.

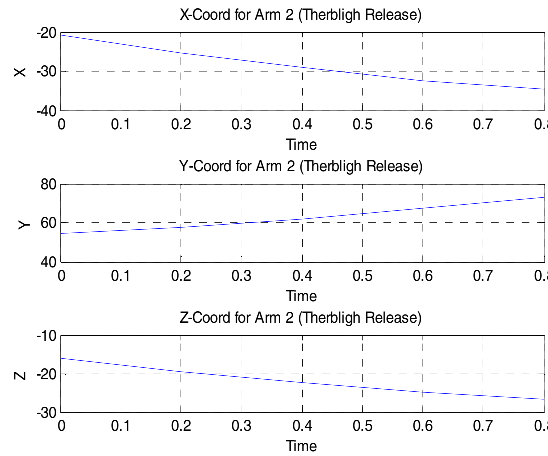

Fig. 11. Progressions of the RELEASE motion of right end-effector projected to X, Y, and Z coordinates.

IV. CONCLUSION

An analysis of human arm motions has been studied as a preliminary result prior to the design of an artificial shoulder-attached double-arm robot to imitate human arms' motions. A forward kinematic model of the arms using Denavit-Hartenberg approach has been done for modelling purpose. Simulations of the model's behavior for each REACH, MOVE, and RELEASE Therbligh motions have been performed. The simulation shows that the REACH motion depends on the 2nd and 4th joint, the MOVE motion depends on the 3rd and 4th joint, and the RELEASE depends on the 4th joint.

For future works, the results in this study will be a cornerstone to design a rehabilitation tool for stroke patients where the weight of arms and motors should have been taken into account as masses instead of L1 and L2. However, some issues to be addressed are dynamics analysis and hardware troubleshooting.

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