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A. E. Alafi [*]　　*M. E. Alami* [**]　　*M. T. Elsaid* [***]

Abstract

This paper presents 3D simulation for human hand according to humanoid (life-like human hand gestures and animations). The simulation of virtual hand model is designed in matlab (using VR builder). The virtual hand model considers 20 degrees of freedom (DOF) for fingers' motion. The fingers' motions are considered around the □ and φ angles around joints. The possibility of catching rigid bodily is taken into account. The simulation enables users to simulate different fingers' motion, modifying, recalling and saving it in data base. Each finger motion is ended by special sound signal to indicate the end of motion. This 3D model can be transformed into robot hand.

Keywords:

3D Simulation, Human Hand, Artificial Hand, Mechanism.

1. INTRODUCTION

Acts of terrorism, war victims and activities of modern living have given rise to an increase the number of human hand harm[1]. Human hand became one of the most hotspot research[3]. It's complex organs of the human body after brain. It's behavior has seen as significant study and research in the engineering field beside medical field. Experimental studies of human grasping in medicine have interest for hand surgery and the design of artificial devices [4] .

A human hand, no different if it's left or right hand, consists of a palm and five fingers: pinky, ring, middle, index and thumb fingers. All the five fingers are connected in parallel to the common wrist base

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frame through the palm. Palm can also be divided into the lower and upper palms[5].

Digital human simulation dissection has reached high levels of visual realist in computer graphics, supporting skeletal constraints, nonlinear flesh deformation, and biomechanical muscle activation models [6]. It can take many forms. Sometime, simulations are used only, and the problem is how to be sure that the gained posture is realism. The simulation can be cinematic or dynamic like. Georges Beurier and et.al Considered the kinematic way. Digital hand models are used for the hand posture simulation [7].

In order to develop a complete model for a human hand and further to produce a realistic motion, the major movable joints that a real human hand possesses is the first step to understand.

This paper presents human hand simulation system. This simulation system depends on truth data about specification of human hand. It’s based on a 3D model of the human hand with focus on bones and joints. The fingers’ motion on two directions is presented. The end of motion is indicated by accompanied sound signal. The simulation is made in matlab(VR builder).

This paper is organized as follows section 1 includs introduction. In section 2 reviewing related work. Human hand data collection is presented in section 3. Section 4 human hand simulation. in section 5 the conclusion and future work are presented.

2. RELATED WORK

Nitesh Bhatiaa et.al. have developed natural simulations using vision as a feedback agent for performing any postural simulations similar to humans. There work didn’t use inverse kinematics. They presented model finally shows vision as a guiding agent for hand reach simulations. Their paper can be used for planning and placement of workspace objects to enhance human task performance [8].

V. Sholukha, et.al. have designed a model-based approach for human motion data reconstruction by a scalable registration method for combining joint physiological kinematics with limb segment poses. The results and kinematics analysis show that model-based lead to physiologically-acceptable human kinematics. It was shown that those tool handles based on the digital human hand model (DHHM) provided a higher overall comfort rating compared to cylindrical handles. It has also been demonstrated that anatomically shaped tool handles based on the developed DHHM can improve user performance and lower the risk of cumulative trauma disorders[9].

Jared Gragg, et.al. have described an optimization-based method for determining an accurate and efficient solution to the posture reconstruction problem. The procedure was used to recreate 120 experimental postures. For each posture, the algorithm minimizes the distance between the simulation model joint centers and the corresponding experimental subject joint centers which is called the mean measurement error [10].

Tong Cui, et.al. have addressed a largely open problem in haptic simulation and rendering: contact force and deformation modeling for haptic simulation of grasping a deformable object with a realistic virtual human hand, especially in power grasps. The virtual hand model consists of meshes of realistic shapes for the finger links and palm of a hand [14].

Markus Hauschild, et.al. have described a virtual reality environment (VRE) to facilitate and accelerate the development of novel systems. In the VRE, subjects/patients can operate a simulated limb to interact with virtual objects. Realistic models of all relevant musculoskeletal and mechatronic components allow the development of entire prosthetic systems in VR before introducing them to the patient. The system in his paper used both by engineers as a development tool and by clinicians to fit prosthetic devices to patients [15].

M. Saiful Bahari et.al. have presented robotic hand having 14 DOF to trigger finger movement. The design combination and integration of fingers will produce a prosthetic hand which has approximately the size of a human hand. Experimental work has been carried out on the prototype robotic hand to ensure the entire rotation angle and movement of each link is functioning as desired [11]. However, they didn't consider the other fingers' motion. The presented paper considered the fingers' motion around x axis and z axis and which yield to 20 DOF. Additionally, the 3D model presented in this paper ended each motion with specific sound signal.

3. HUMAN HAND DATA COLLECTION

The hand is the multi-fingered extremity at the end of the arm. It is one mean by which human had changed the world by creating gigantic buildings and machines, tiny electronics, and high-fived each other at those accomplishments.

Hands are capable of a wide variety of functions, including gross and fine motor movements. Gross motor movements allow human to pick up large objects or perform heavy labor. Fine motor movements enable human to perform delicate tasks, such as holding small objects or performing detailed work.

The complex abilities of the hand are part of what make humans unique like finger print. This ability provides us with the dexterity to use tools. It also gives us a forceful grip.

3.1 Human hand relative components measurements

Human hand parts are wrist, palm and fingers (thumb, index(first), middle, ring and little (pinky)) [18]. The hand components are shown in figure 1.

- Fingers are digits that extend from the palm of the hand. The fingers make it possible for humans to grip the smallest of objects.
- Palm is the bottom part of the hand body.
- Wrist is the connection joint between the arm and the hand. The wrist enables hand movements.

Figure 2 shows the human hand parts ordered for describing the hand parameters given in table 1 which is inspired from ref [19]. The relative bones' length is described in table 1 where Lo = L2 + P.

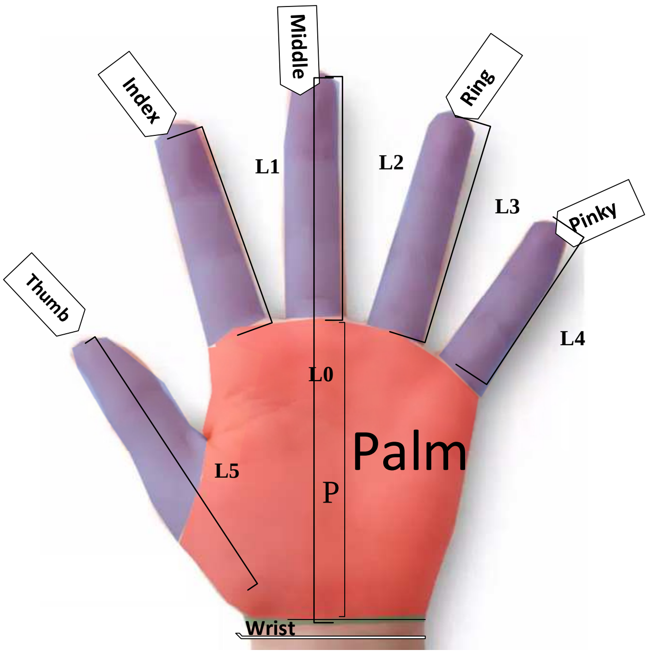


Figure 1: The human hand components.

Figure 2: Human hand ordered parts.

TABLE 1: Hand parameters

Fingers Name	Parts	Bones lengths		
		(mm)	Relative length	%
Index	L11	25.1	L11/L0×100	13.92
finger	L12	21.5	L12/L0×100	11.92
	L13	26.9	L13/L0×100	14.91
Total	L1	73.5	L1/L0×100	40.76
Middle	L21	27.2	L21/L0×100	15.08
finger	L22	24.3	L22/L0×100	13.47
	L23	30.3	L23/L0×100	16.80
Total	L2	81.8	L2/L0×100	45.36
Ring	L31	25.2	L31/L0×100	13.97
finger	L32	20.9	L32/L0×100	11.59
	L33	27.2	L33/L0×100	15.08
Total	L3	73.3	L3/L0×100	40.65
Little	L41	18.9	L41/L0×100	10.48
(Pinky)	L42	15.6	L42/L0×100	8.65
finger	L43	16.8	L43/L0×100	9.31
Total	L4	51.3	L4/L0×100	28.45
Thumb	L51	26.9	L51/L0×100	14.91
finger	L52	33.5	L52/L0×100	18.58
	L53	38.9	L53/L0×100	21.57
Total	L5	99.3	L5/L0×100	55.07
Palm	P	98.5	P/L0×100	54.63

3.2 Human hand parts

Appropriate simulation of human hand is necessary to study human hand from biological point of view. The hand parts are composed of bones and joints.

Table 2 shows the bones and joints of all fingers except the thumb. Table 3 shows the bones and joints of the thumb finger [17]. Figure 3 shows the detailed bones and joints of human hand fingers.

TABLE 2: Bones and joints of the fingers except Thumb [17].

Bones:	**Joints:**
• Proximal Phalanx – MP	• Metacarpal phalangeal – MCP
• Middle Phalanx - PP.	• Proximal Interphalangeal – PIP
• Distal Phalanx – DP.	• Distal Interphalangeal – DIP

TABLE 3: Bones and joints thumb finger [17].

Bones:	**Joints**:
• metacarpal trapezoid- MC	• carpometacarpal– CMC
• Proximal Phalanx - PP.	• metacarpophalangeal – MCP
• Distal Phalanx – DP.	• Distal Interphalangeal – IP

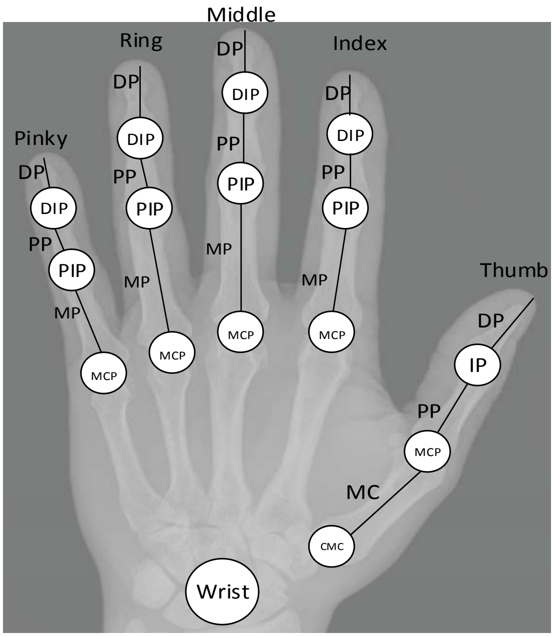


Figure 3: Human hand bones and joints.

3.3 Human hand bones motion limits

Human hand fingers have two motions. One of them occurs around x axis while the second occurs around z axis as shown in figure 4.

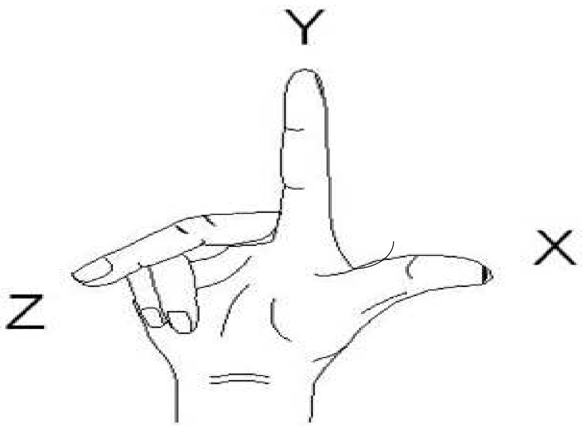


Figure 3: Human hand axis.

3.3.1 First motion

Frist motion around the finger joints (MCP, PIP and DIP) with 3 angles. The middle finger for example has 3 angles (ɵ 1, ɵ 2 and ɵ 3) as shown in figure 5. Kinematic structure of the virtual hand is shown in table 4.

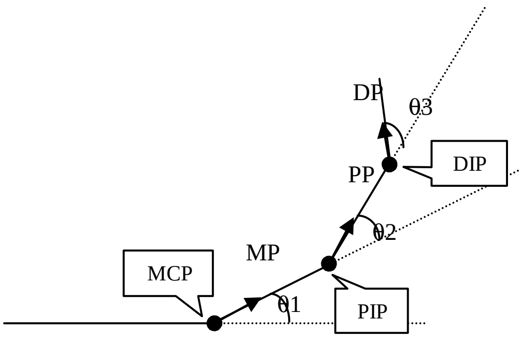


Figure 4: Middle bone motion angles.

Table 4: Kinematic structure of the virtual hand [20]

Joint connection		□ Range	
All fingers except Thumb		**Limits**	
1	MCP	ɵ 1	-20 – +90
2	PIP	ɵ 2	0 – +90
3	DIP	ɵ 3	-20 – +90
Thumb finger			
1	TM	ɵ 1	-20 – +90
2	MCP	ɵ 2	-40 – +40
3	IP	ɵ 3	0 – +80

3.3.2 Second motion

Each finger can move with specific angle (φ1, φ2, φ3, φ4 or φ5) with its neighbor finger as shown in figure 6. Kinematic structure of the virtual hand is shown in table 5.

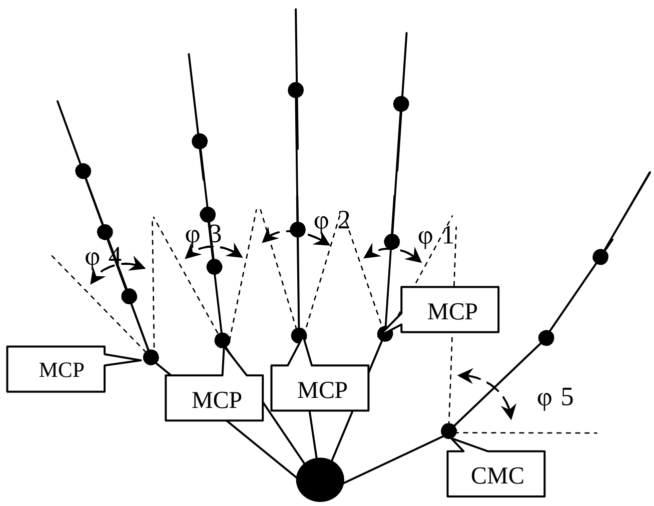


Figure 6: Fingers motion angles.

Table 5: Kinematic structure of the virtual hand

Joint connection		φ Range
All fingers except Thumb		**Limits**
1	Knuckle - Palm	-25 – +25
Thumb finger		
1	Proximal - Palm 2	-60 – +60

4. HUMAN HAND SIMULATION

Human hand simulation system has two stages. These stages are human hand modeling and virtual hand interfacing.

The virtual hand interfacing is composed of starting simulation, virtual hand fingers motion controlling, controlling virtual hand view-points and creation and retrieval of virtual hand.

4.1 Human hand modeling

Since the human hand includes 15 bones and 15 joints these two numbers must be considered in simulation. During modeling stage 15 cylinders and 12 ellipsoids will be included. The palm is represented by two boxes.

VR-build2[] is used for simulating the cylinders, ellipsoids and boxes. Each of these components has specific properties such as (translation, rotation, name and color). The translation values of each node can be adjusted as shown in figure 7. Table 6 shows all of these translation values.

Rotation values of each node can be adjusted as shown in Figure 7. Table 7 shows all of these rotation values.

The inter-connections of these components give the virtual hand model as shown in figure 9.

The virtual hand can be observed via 7 cameras (for top view, bottom view, right view, left view, front view, back view and for main view) as shown in figure 10.

The nodes and viewpoints are the virtual world nodes. The virtual world nodes are shown in figure 11. The virtual hand with the previous simulation objects is exported to matlab for the controlling processes.

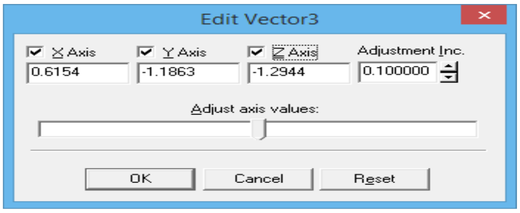


Figure 7: Translation of one-part human hand.

Table 6: Translation property of hand parts

Fingers Name	Finger's Parts	Translation		
	Name	x	y	z
Pinky	DP			
	DIP			
	PP	81.51	-73.75	5.539
	PIP	١٠٠-	٧٩.٤٦٥-	٦.٠٧
	MP	٩٣.١٨	٣٣.٦٤-	٧.٢٦٢
	MCP	١١٣-	١٧.٢١٢-	٨.٧٩
Ring	DP			
	DIP			
	PP	56.47	-84.09	2.744
	PIP	-68.95	-47.889	-1.2
	MP	65.27	-6.564	2.345
	MCP	-78.41	-16.195	2.71
Middle	DP			
	DIP			
	PP	29.71	-39.53	2.74
	PIP	-37	-422	2.5
	MP	33.68	1.723	2.89
	MCP	-39.36	-67550	2.193
Index	DP			
	DIP			
	PP	0.7002	-32.54	1.445
	PIP	0	-39	0
	MP	2.012	0.0146	3.273
	MCP	-2	-10	3
Thumb	DP			
	IP			
	PP			
	MCP			
	MC	-64.93	-107.6	7.19
	CMC	-36.635	37.308	-20.718

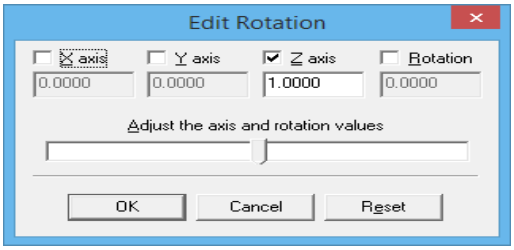


Figure8: Rotation of one-part human hand.

Table 7: Rotation property of hand parts

Fingers Name	Finger's Parts Name	Rotation		
		x	y	z
Pinky	DP	0	0	1
	DIP	٠	٠	١
	PP	٠	٠	١
	PIP	٠	٠	١
	MP	٠	٠	١
	MCP	٠	٠	١
Ring	DP	0	0	1
	DIP	0	0	1
	PP	0	0	1
	PIP	0	0	1
	MP	0	0	1
	MCP	0	0	1
Middle	DP	0	0	1
	DIP	0	0	1
	PP	0	0	1
	PIP	0	0	1
	MP	0	0	1
	MCP	0	0	1
Index	DP	1	-0.447	0
	DIP	-0.8944	-0.447	0
	PP	0	0	1
	PIP	0	0	1
	MP	0	0	1
	MCP	0	0	1
Thumb	DP	0	0	1
	IP	0	0	1
	PP	0	0	1
	MCP	0	0	1
	MC	0	0	1
	CMC	0.9036	-0.3947	0.664

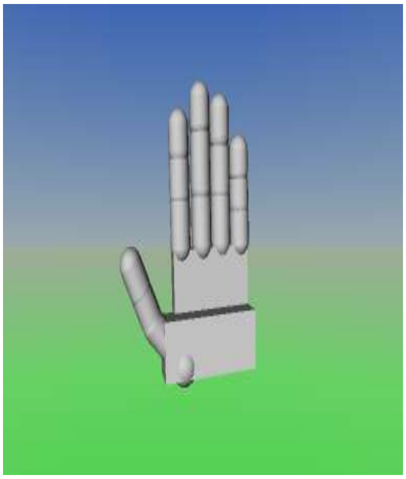


Figure 9: Parts of human hand.

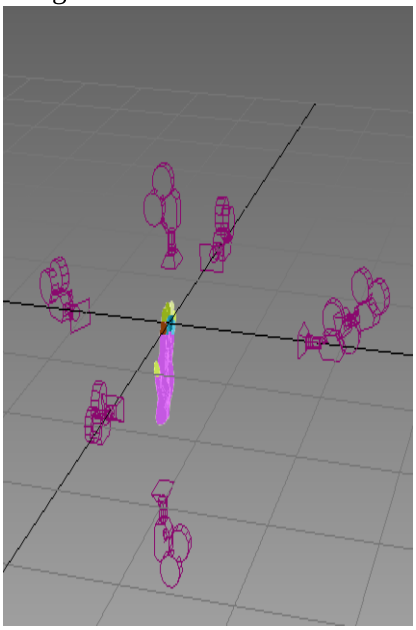


Figure 10: Viewpoints for hand simulation objects.

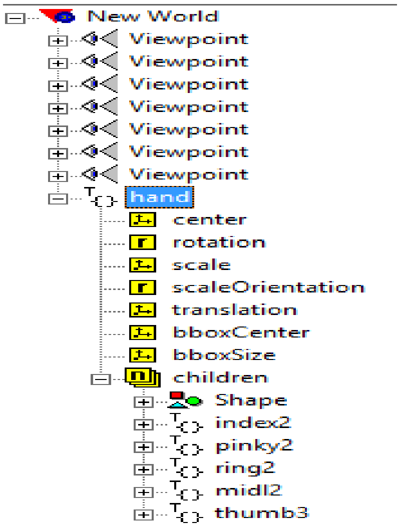


Figure 11: Nods tree of human hand parts.

4.2 Virtual hand interfacing

The proposed system is composed of: displaying the virtual hand rendered from different viewpoints (with various virtual cameras), controlling the virtual hand motion, creating hand gestures and animations, and recording the animation in database for feedback in the system.

The graphical user interface (GUI) used to facilitate the process of generating hand gestures and animations. The generalized human hand simulation layout includes three interconnected subsystems. These subsystems are virtual hand starting and displaying, virtual hand fingers motion controlling, virtual hand view-points controlling and virtual hand creating and retrieval as shown in figure 12.

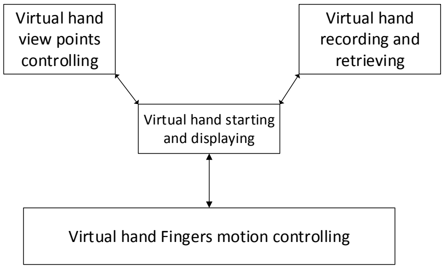


Figure12: The environment of human hand simulation system.

The proposed GUI is shown in figure 13.

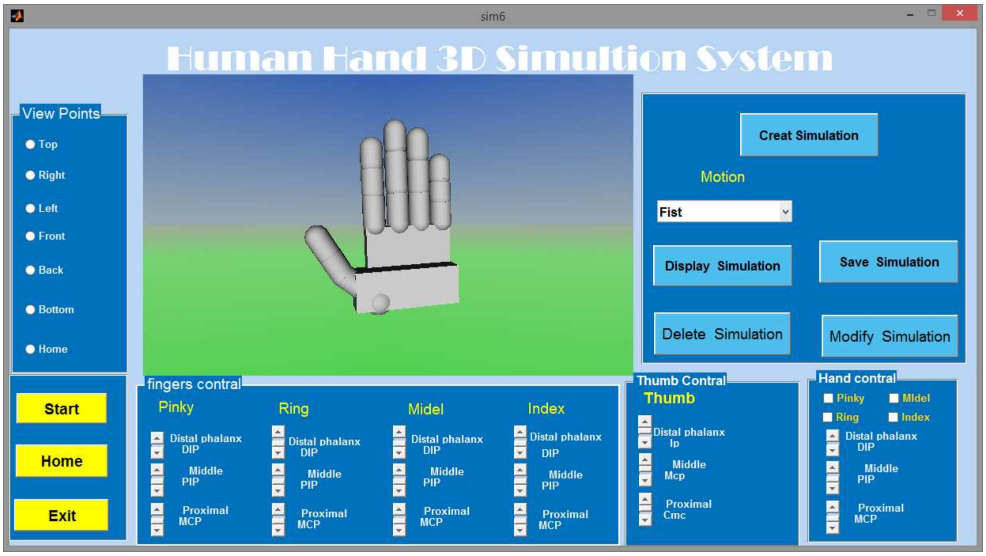


Figure13: Screen shot of Hand simulation system

4.2.1 Starting simulation

This part is concerned with calling the virtual hand and displaying it. It enables the user to see the different process made on this virtual hand (in different directions). It can rest the virtual hand to its original case.

4.2.2 Virtual hand fingers motion controlling

The control processes of virtual hand fingers' motions can be controlled via three control panels fingers control, thumb control and hand controls as shown in figure 14.

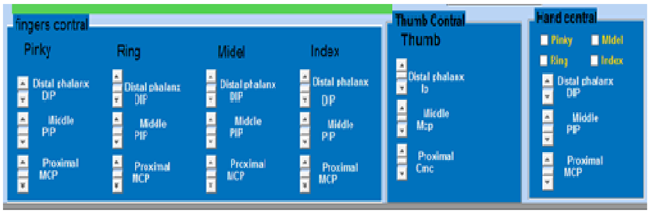
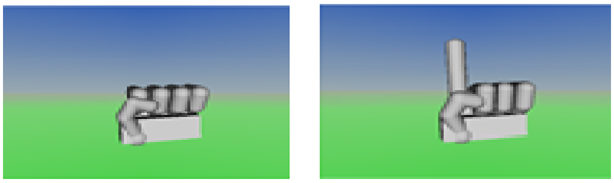
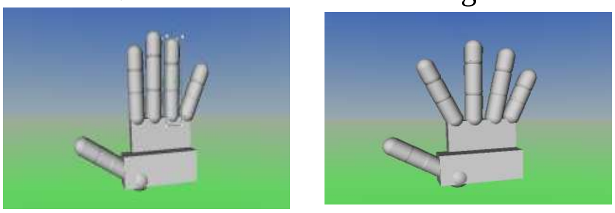


Figure 14: Virtual hand fingers motion controlling.

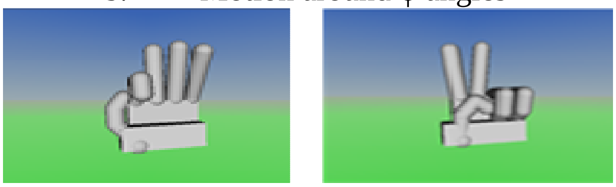
The fingers’ motions are divided into: motions around □ angles, φ angels, both (□ and φ) and catching a rigid body. These motions are controlled according to the permissible angles explained in tables 4 and 5. Figure 15 a, b, c and d shows the four fingers’ motions.



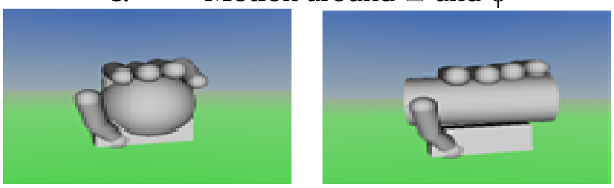
a. Motion around □ angles



b. Motion around φ angles



c. Motion around □ and φ



d. Motion for catching

Figure 15: The movement of human hand simulation

Controlling each of the virtual hand fingers' motion is accompanied with sound signal as an indicator for the end of motion. This is quite suitable when The hand fingers' motion is assembled in robot hand for example.

4.2.3 Controlling virtual hand view-points

Each motion can be viewed in seven directions by seven cameras built in VR-builder. These view-points explain the virtual hand simulation to the users. The controls of the seven cameras are shown in figure 16.

Figure 16: Virtual hand view-points controlling.

4.2.4 Creation and retrieval of virtual hand

The simulation processes result different types of virtual hand finger motions. The simulated shapes can be saved, displayed, modified and deleted. This module enables the previous virtual hand simulation processes as shown in figure 17.

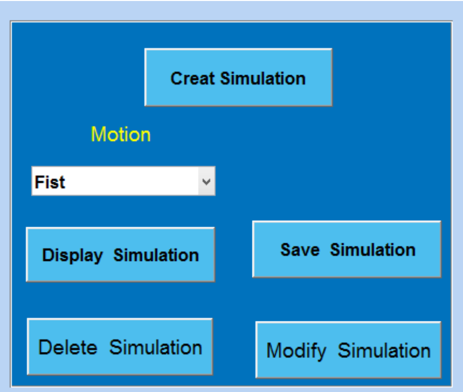


Figure 17: Virtual hand creating and retrieval.

5. CONCLUSIONS and FUTURE WORK

The virtual hand simulation is crucial nowadays since the terrorism victims increase as due to Violence. This 3D virtual hand model simulates the hand fingers according to humanoid. The human hand fingers' motion occurs around two axis z and x. The system is provided with sound signal generator to indicate the ended fingers' motion. This system can be realized as a part of total hand model in robots.

The future work is to simulate the fingers' forces when catching and pressing a rigid body.

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