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Matlab Toolbox for Kinematic Analysis and Simulation of Dexterous Robotic Grippers

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Abstract

Robot simulators have supported the science of robotics for a long period and have been an indispensable tool for understanding, planning, designing and programming of educational and industrial robots. These soft tools allows the users to program and test their applications without using the real hardware or even building it since such tools allow the analysis of behaviours and performance beforehand. Some of these soft tools have already been designed and developed for professional as well as educational and research purposes by researchers. However, the majority of these tools are specifically designed for serial manipulators and simulation tools for robotic grasping is rather limited e.g Graspit!, OpenGRASP, SynGrasp, and hence there is a need to develop a general purpose software package for performing different analyses on dexterous robotic hands.
In this research work, a new MATLAB based dexterous robotic gripper toolbox is developed with GUI based simulating environment for Kinematic analysis and additional features with inbuilt library of various dexterous grippers of Robot. This toolbox has capabilities like Hand modeling, Grasp definition, Grasp modeling, Grasp analysis and Graphics to support representation of various commercially available existing dexterous grippers and has provision and flexibility to accommodate any newly developed hand. The library of toolbox has different parameters like Denavit - Hartenberg parameters, finger size, and joint angles etc. which are used for kinematics of various dexterous grippers. Form closure analysis is a special feature that has been included for understanding the actual positioning and orientation of fingers of dexterous grippers according to the object position. The library of proposed toolbox has detailed definition of objects to make form closure by various models of dexterous grippers.

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Keywords: Matlab robotic gripper toolbox, Dexterous grippers, Grasp planning, Kinematic analysis, Grasp simulation

1. Introduction

Kinematic structure, real-time motion control and axis drive mechanism design helps into focus on major manipulation performance characteristics like reach and dexterity, quickness, payload, and precision. Reach explains

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the motion of the robot links in the space and dexterity indicates the angular displacement of a joint. reach and dexterity of the robot are decided by the three axes of the arm. Robot simulators have supported the science of robotics for a long period and have been an indispensable tool for understanding, planning, designing and programming of educational and industrial robots. These soft tools allows the users to program and test their applications without using the real hardware or even building it since such tools allow the analysis of behaviours and performance beforehand. In robotics research, simulators have an important role in the development and demonstration of algorithms and techniques in areas such as path planning, grasp planning, mobile robot navigation and others. There are many benefits of using theses soft tools such as they facilitate testing and tuning of conceptual mechanisms under varying user defined conditions and constraints. Second, they avoid use and wear of expensive and complex robotic structures. Finally they are cheaper than the real robots and manipulators. Some of these soft tools have already been designed and developed for professional as well as educational and research purposes by researchers. However, the majority of these tools are specifically designed for a particular application however some are successful attempts to develop general purpose robot software packages. Some are independent software while others are plugin types. The primary contribution of these software packages is the automation and simplification of the robot modeling process which is important for correct robot design and control. In addition, the easy to use GUI and simplified models allow rapid prototyping and simulation of robots and control design/validation. These soft tools allow user to easily create and manipulate data type fundamental to robotics such as Denavit and Hartenberg parameters, homogeneous transformations, quaternions and trajectories which are necessary to represent 3D position and orientations. Functions available in these soft tools include forward and inverse kinematics and forward and inverse dynamics. These tools are based on general method of representing the kinematics and dynamics of serial link manipulator. However, the majority of these tools are specifically designed for serial manipulators and simulation tools for robotic grasping is rather limited e.g OpenGRASP[1], Graspit![2,3], SynGrasp[4], and hence there is a need to develop a general purpose software package for performing different analyses on dexterous robotic hands.

1.1. OpenGrasp

It is a modular architecture based toolkit for simulation of grasping and dexterous manipulation. The user can generate and also shifts the models developed. This toolkit is upgrade or improved version of OpenRAVE [1]. This is enhanced by the Robot Editor, adopting the COLLADA file format, and Physical Abstraction Layer for flexibility and standardisation. OpenRAVE designed for the autonomous robot applications and having three layers i.e. a core, a plugins layer for interfacing to other libraries and scripting interfaces for easier access to functions. The key aspects of robot editor are geometric modeling, semantic modeling, dynamic modeling, and conversion formats. The significant application of OpenGRASP is planning and grasping, it is based on Medial axis of object and to reduce candidate grasp search space. The robot editor generates different models like SAH hand, SDH hand, Barrett hand, Kuka KR5 sixx R850 arm, hand of Otto bock, Shadow hand, and humanoid robot ARMAR-III.

1.2. Graspit!

It is an ideal environment for grasp analysis and planning, and it can serve as a test bed for new grasp evaluation, grasp synthesis, and manipulation planning algorithms. It is possible to test these algorithms much more quickly and for more hand designs than would be possible in the lab using an actual robot. Ultimately, the planning for an actual grasping task can be performed in simulation and then carried out on a physical system. It is a simulator which will accommodate arbitrary hand and robot designs. It can also load objects and obstacles of arbitrary geometry to populate an entire simulation world. The 'GraspIt!' [2] engine includes rapid collision detection and contact determination system that permits a user to interactively manipulate a robot or an object and make contacts between them. Once a grasp is formed, one of the key features of the simulator is the set of grasp quality matrix. Each grasp is evaluated with numeric quality measures, and visualization methods enable the user to check the weak point of the grasp and make arbitrary 3D projections of the 6D grasp wrench space.

'GraspIt!' [3] have features like 3D user interface permitting the user to check and interact with a virtual world containing robots, objects and obstacles. It also consist of dynamics engine, grasp planning, facilities, computation of numerical grasp quality matrices and visualization methods for the Grasp Wrench Space, support for Soft Finger Contacts, support for low-dimensional hand posture subspaces, a library of robotic hand models for interaction with hardware and sensors, like a Barrett hand, Flock of Birds tracker and Cyberglove, a flexible robot definition that makes it possible to import new robot designs, a fast collision detection and contact determination. System and a simple trajectory generator and control algorithms that compute the joint forces are necessary to follow the trajectory.

1.3. Syngrasp

Syngrasp [4] is an independent robotic toolbox developed for analysis of grasping of human hand as well as robotic hands. It gives a graphical representation of models of hand an anthropomorphic hand, a 3-fingered hand, a modular hand and the DLR/HIT II Hand. This toolbox has capabilities like hand modeling, Grasp modeling, Grasp analysis and Graphics to support representation of Manipulator and objects of arbitrary shapes. The tool is designed to integrate in the hand model a kinematic coupling between joints, as those provided in the synergistic organization of human hand or due to the mechanical or control constraints realized on the robotic hands. The toolbox functions were developed to allow a simple and intuitive analysis of the main grasp properties, e.g. controllable force and motion, manipulability, grasp quality measures.

2. Various robotic analyses

The steps involved in performing analysis include:
1. Representing 3D translation and Orientation
2. Kinematics
3. Trajectories
4. Dynamics
5. Grasp Planning and Grasp Analysis
6. Advanced features like Remote operation support, Augmented reality features, Collision detection
7. Simulation

3. New Toolbox development framework

A MATLAB based Toolbox viz. 'DXGToolbox' has been developed in this research work to perform grasp related analyses. The steps followed in the development are shown in figure 1.

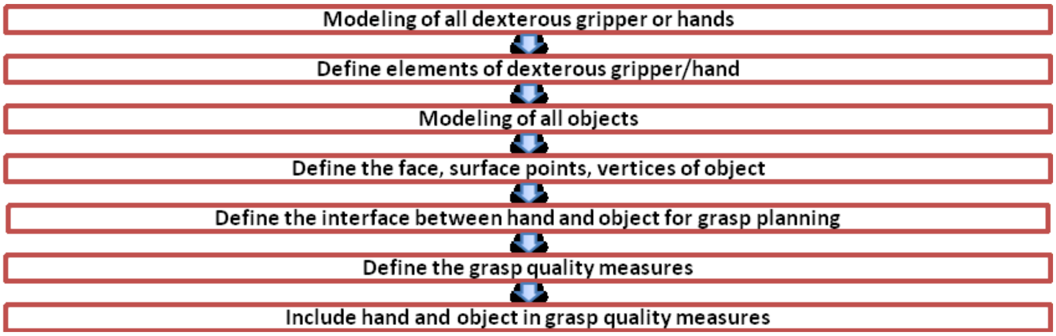


Fig. 1 Flow chart of steps utilized for developing DXGToolbox

DXGToolbox comprises of 6 modules viz. DXGToolbox Functions, User Hand Definition, Existing Grippers Model, Object Definition, Grasp Quality Measure and Grasp Modeling Window. All these modules are labeled and depicted in figure 2 while the connectivity and hierarchy is depicted through a flow chart shown in figure 3.

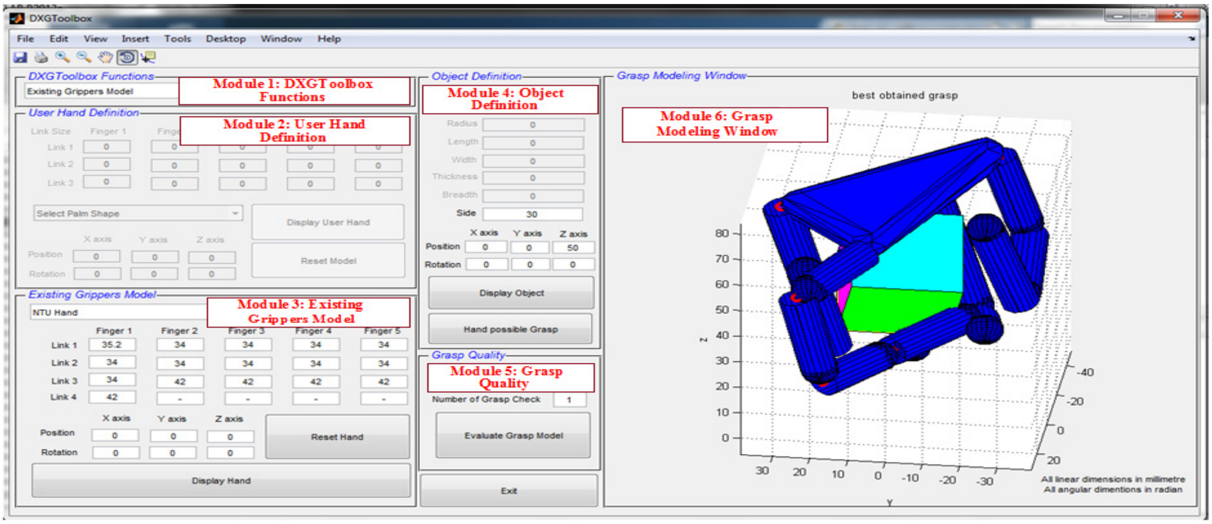


Fig.2 Six Modules of DXGToolbox

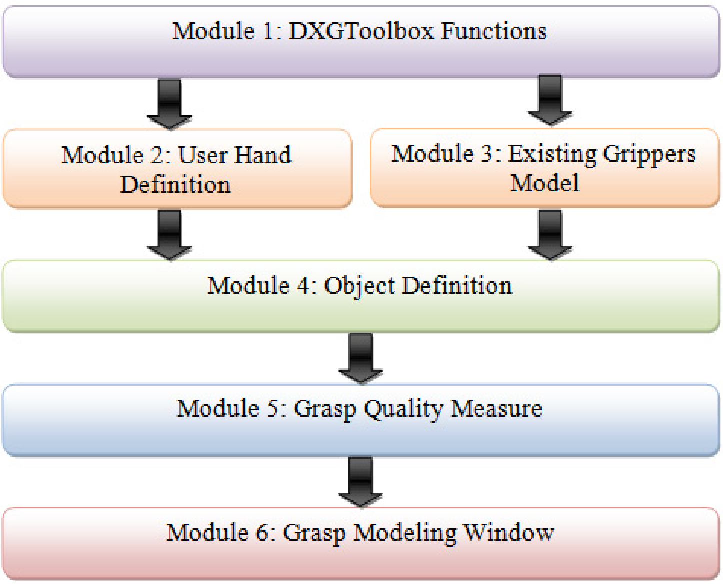


Fig. 3 Flow chart of module of DXGToolbox GUI

3.1. Module 1: DXGToolbox Functions

A visible popup menu available in Module 1 the ‘DXGToolbox Functions’ has an instruction ‘Select DXGToolbox Function’. On clicking this, two options appear on the screen i.e:

- User Hand Definition
- Existing Grippers Model

Through this popup module, the user can access ‘User Hand Definition’ (Module 2) option and ‘Existing Grippers Model’ (Module 2) option, which are explained in next section.

3.2. Module 2: User Hand Definition

User has a choice to decide about different hand elements like number of fingers, links length and palm shapes. All the sizes are in millimetre. User can select the palm shapes as listed below:

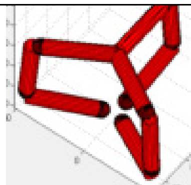
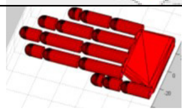
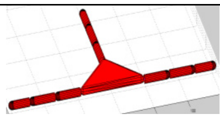
1. Circle
2. Rectangle, and
3. Trapezium

After selecting the palm, user can select maximum number of five fingers made up of maximum of three links. According to the requirement, user can feed number of fingers and the corresponding link sizes. It is not necessary to fill in all the cells. There are other options in the module, like hand position and its orientation. The position and rotation details can be feed in millimeter from the grid origin (0, 0, 0) and in radian from 0 to 1 respectively. On clicking the display user hand, the model of user hand will get displayed on the GUI window (Module 6). The button 'Reset Model' orients back to default Module 2.

3.3. Module 3: Existing Grippers Model

In this fragment of toolbox, data related to nine models of existing industrial dexterous grippers is available (as given in table 1). These nine hands are Barrett hand [5-7], Paradigmatic hand [8,9], Modular hand [10], DLR 2 hand [11,12], GIFU hand3 [13,14], KH hand S1[15,16], Shadow hand [17,18], HIRO hand 3 [19,20], NTU hand [21,22]. The number of fingers and link lengths information are also displayed on the screen as per the details provided in table 2. User can select a particular hand by clicking default instruction 'Choose Hand'. By clicking 'Display Hand' button, the equivalent hand model gets displayed in the GUI window of Module 6. There are other options available for positioning and orientation of selected gripper with respect to X-Y-Z axes. The but-ton 'Reset Hand' brings back to the default Module 3. User can also define his own dexterous hand and perform all the stated analyses.

Table 1. Various shapes and configuration of industrial dexterous gripper and their equivalent in DXGToolbox

Hand	**Actual Configuration**	**Equivalent model used in DXGToolbox**
Barrett Hand [5-7]		
Paradigmatic Hand [8,9]		
Modular Hand [10]		

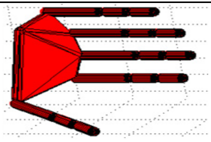
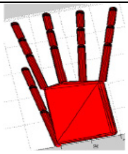
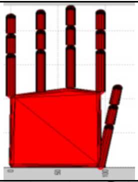
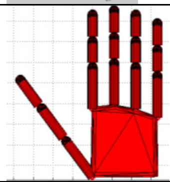
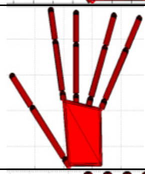
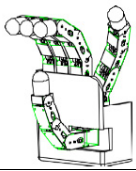
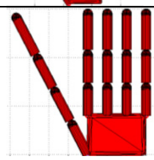
DLR 2 Hand [11,12]		
GIFU Hand 3 [13,14]		
KH Hand S1 [15,16]		
Shadow Hand [17,18]		
HIRO Hand 3 [19,20]		
NTU Hand [21,22]		

Table 2. Dimensions for DH parameter of various industrial dexterous grippers considered

	Hand Models	Barrett Hand	Paradigmatic Hand	Modular Hand	DLR 2 Hand	GIFU Hand 3	KH Hand S1	Shadow Hand	HIRO Hand 3	NTU Hand
Finger 1 Link size	L1	50	25	38	55	70.5	62.5	38	13	35.2
	L2	50	15	38	25	50	29	32	72	34
	L3	-	10	31	25	36.5	29	27.5	45	34
	L4	-	-	-	-	-	-	-	-	42
Finger 2 Link size	L1	50	37	38	55	70.5	62.5	45	13	34
	L2	50	30	38	25	32	29	25	72	34
	L3	-	15	31	25	32.5	29	26	45	42
Finger 3 Link size	L1	50	40	38	55	70.5	62.5	45	13	34
	L2	50	35	38	25	32	29	25	72	34
	L3	-	17	31	25	32.5	29	26	45	42
Finger 4 Link size	L1	-	37	-	55	70.5	62.5	45	13	34
	L2	-	30	-	25	32	29	25	72	34
	L3	-	15	-	25	32.5	29	26	45	42
Finger 5 Link size	L1	-	27	-	55	70.5	62.5	45	13	34
	L2	-	25	-	25	32	29	25	72	34
	L3	-	10	-	25	32.5	29	26	45	42

3.4. Module 4: Object Definition

This module appears after the completion of Module 2 and 3.This module defines the object according to its size, position and orientation. Popup menu shows a default instruction 'Select Grasp Object Shape', and six different objects appear in the list. On selecting one of the mentioned shapes, the corresponding variable/s appears on the screen. The six selected standard shapes along with their function file names are given in table 3.

Table 3. Functions files of DXGToolbox for various shapes

Shape	Function files in DXGToolbox
Sphere	DXGobjsph
Cube	DXGobjcube
Cylinder	DXGobjcyl
Slab	DXGobjslab
Plate	DXGobjplate
Cuboid	DXGobjcboid

A user friendly option provided for deciding the shape as per table 3. This provides option to feed the numerical values for variables and decides both the position as well as orientation of the object. On clicking the button 'Display Object', the object will appear on the GUI window with already selected hand. If, in case, object and hand are in the specified position or not acquiring the common space points, then a message box 'Cannot place the object in desired position' would appear.

3.5. Module 5: Grasp Quality

This is the most vital module of the toolbox. Here the grasp quality measures are calculated for finding the grasp relation between the hand and the grasp object. There are six different quality measures that are taken in account in this toolbox. The grasp quality measures utilized in this toolbox are specified in table 4.

Table 4. Various Grasp quality measures used in DXGToolbox

Grasp Quality Measure	Formulae Used	Function and its programming
Minimum singular value of G	$Q = \sigma_{min}(G)$	DXGmsingularvg(G) SminG = sqrt(eigs(G*(G'),1,'sm'));
Grasp isotropy index	$Q = \frac{\sigma_{min}(G)}{\sigma_{max}(G)}$	DXGgii (G) SmaxG=sqrt(eigs(G*(G'),1,'lm')); SminG = sqrt(eigs(G*(G'),1,'sm')); Ii=SminG/SmaxG;
Distance to singular configurations	$Q = \sigma_{min}(H)$	DXGdsconfig(G,J) Gc=G'*inv(G*G'); HO=Gc'*J; SminHO=sqrt(eigs(HO*(HO'),1,'sm'));
Volume of the manipulability ellipsoid	$Q = k\sqrt{\det(HH^T)}$	DXGmanipEllipsoidVolume(G,J) Gc=G'*inv(G*G'); HO=Gc'*J; VSHO=sqrt(eig(HO*(HO'))); VE=VSHO(1)*VSHO(2)*VSHO(3)*VSHO(4)*VSHO(5)*VSHO(6); VE=sqrt(det(HO*(HO')));
Uniformity of transformation	$Q = n_c(H) = \frac{\sigma_{min}(H)}{\sigma_{max}(H)}$	DXGuot(G,J) Gc=G'*inv(G*G'); HO=Gc'*J; SmaxHO=sqrt(eigs(HO*(HO'),1,'lm')); SminHO=sqrt(eigs(HO*(HO'),1,'sm')); Ut=SmaxHO/SminHO;
Volume of the ellipsoid in the wrench space	$Q = k\sqrt{det(GG^T)}$	DXGVolellwenchspace(G) VGHO=sqrt(eig(G*(G'))); VE=VGHO(1)*VGHO(2)*VGHO(3)*VGHO(4)*VGHO(5)*VGHO(6); VE=sqrt(det(G*(G')));

3.6. Module 6: Grasp Modeling Window

The module provides a MATLAB based GUI window for analyzing the mathematics related to grasp quality. This also gives a detailed view of object grasped by the hand. Module 2 and Module 3 generate the hand model, while Module 4 provides grasp object model. Toolbox performs all operations in a sequential manner. Module 6 provides an interactive view of hand and object view.

4. Results and Conclusion

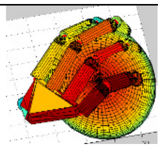
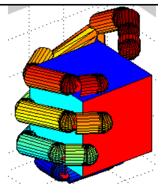
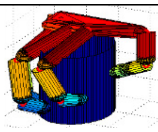
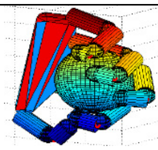
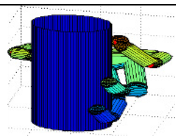
In this work a MATLAB based tool box has been developed that can perform various analyses related to grasp modeling, grasp planning and grasp quality evaluation using a single platform as depicted by a flowchart in figure 1. In this toolbox nine different industrial dexterous hands are included and grasping is performed using six different standard objects. The tool box performs activity listed in table 5 along with their MATLAB files and functions. A GUI based environment facilitates the user to use all the modules of the software in a sequential manner to analyze any grasp related task. The toolbox utilizes six grasp quality measures as listed in table 6. User can also have facility to define his own dexterous hand model and perform all sorts of stated analyses.

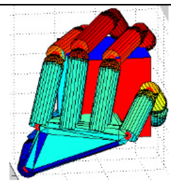
Table 5. List of files & functions used in DXGToolbox for a specific activity

Modeling of all dexterous gripper or hands	DXGhandBarrett DXGhandparadig DXGhandmodular DXGhandDLR2 DXGhandGIFU3	DXGhandKHS1 DXGhandshadow DXGhandHIRO3 DXGhandNTU DXGhandnew
Define elements of dexterous gripper/hand	DXGdevfin DXGdevhand DXGfingerchk DXGcontip DXGmatDH DXGxaxrot DXGyaxrot	DXGjoint DXGhanddisplace DXGhandchk DXGcrehand DXGcrelink DXGcrepalm DXGcolorfreeze

	DXGzaxrot	
Modeling of all objects	DXGobjsph	DXGobjcboid
	DXGobjcube	DXGfincon
	DXGobjcyl	DXGhomtran
	DXGobjslab	DXGlinkseg
	DXGobjplate	
Define the face, surface points, vertices of object	DXGinterlink	DXGfacecyl
	DXGsechk	DXGfaceslab
	DXGseconsph	DXGfaceplate
	DXGfacecube	DXGfacecboid
Define the interface between hand and object for grasp planning	DXGindcube	DXGpobjcyl
	DXGpsolidobj	DXGpobjslab
	DXGindslab	DXGpobjplate
	DXGindplate	DXGpobjcboid
	DXGindcboid	DXGdobjsph
	DXGpobjcube	DXGdobjcyl
Define the grasp quality measures	DXGmsingularvg	DXGmanipEllipsoidVolume
	DXGgii	DXGuot
	DXGdsconfig	DXGVolellwenchspace
Include hand and object in grasp quality measures	DXGplangrp	DXGdevobj
	DXGpointcloudgen	DXGmatsel
	DXGinitialpointhand	DXG3dpointplane
	DXGgrphand	DXGhselmat
	DXGhandcontact	DXG3dvetnor
	DXGjacmat	DXGmatgrp
	DXGmatskew	DXGredind
	DXGobjcontactpoint	DXGmatgtilde
	DXGdetectface	DXGsortgrpplan

Table 6. List of Grasp quality measures and their outputs

Grasp Quality Measure	GUI window display
Minimum singular value of G	
Grasp isotropy index	
Distance to singular configurations	
Volume of the manipulability ellipsoid	
Uniformity of transformation	

Volume of the ellipsoid in the wrench space	

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