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Design and Simulation of 3 Fingered Underactuated Gripper

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***Abstract*—The paper proposes to design and develop an underactuated three fingered gripper with 7 degrees of freedom. The objective is to simulate a flexible gripper, able to grasp objects of a variety of shapes, using ROS framework. A gripper is designed which is driven by four motors - one each for the three fingers, and a fourth motor to emulate the opposing action of two fingers. The prototype is designed to be used as an end effector of ABB IRB 120 manipulator. The paper discusses the different stages of design and simulation involved – specification definition, CAD modeling, torque computation for motor selection and simulation of the model in Gazebo.**

***Index Terms*—Underactuation, Three fingered gripper, Gazebo, ROS**

I. Introduction

The robot end effector is the device with which the robot arm interacts with the environment around it. The actions of the gripper vary with the tasks. For example, an object with circular cross-section cannot be held properly with a two-fingered gripper, atleast not with indeterminacy of position. Since circular and rectangular objects partly or wholly characterize the vast majority of parts encountered in industry in general, a "universal" robot gripper must be able to handle these effectively.

Underactuation in robotics means the system has fewer actuators than the degrees of freedom of the robot [1]. Underactuated robotic hands are the intermediate solution between robotic hands for manipulation and robotic grippers. Robotic hands for manipulation have the advantages of being versatile, guarantee a stable grasp, but they are expensive, complex to control and with many actuators. Robotic grippers have simplified control, fewer actuators, but they have the drawbacks of being task specific, and perform an unstable grasp. [2].

An underactuated mechanism allows a more natural way of grasping of objects in a manner similar to that obtained by the human hand. Schlesinger has defined the six basic prehensile patterns of the human hand from an anthropomorphic point of view. [3] The mechanical equivalents of such a system require a minimum of three fingers. Hence, three fingers seem to be essential for the manipulation of objects in general.

II. Methodology

The entire work is split into two phases. In the modeling phase, the structure and the mechanism of the gripper is designed keeping in mind the requirements of the gripper. In the simulation phase, the working of the gripper in real world is emulated using ROS (Robot Operating System) packages and the simulation environment Gazebo.

III. Modeling

A. Gripper Specifications

A 3 fingered gripper with a total 7 DOF is proposed in the paper. Each finger has 2 DOF and the symmetrical movement of a pair contribute to the extra DOF. [4]

The gripper is designed in such a way that it is compatible with ABB IRB 120 manipulator. As per the specifications given in the IRB 120 datasheet [5], an end effector, weighing a maximum of 3kg including payload, can be used.

As per the requirements, the gripper specification is finalized as follows:

TABLE I
Gripper Specifications

No: of fingers	3
DOF	7
No.of links in each finger	3
No.of joints in each finger	2
Length of base link	52mm
Length of middle link	70mm
Length of distal link	56mm
θ_1	0 to 50°
θ_2	0 to 140°
Payload	Maximum 250g

B. Kinematics

The kinematics of each finger is analysed separately and then coupled at the end to obtain the kinematics of the gripper as a whole. For this purpose, the general Denavit-Hartenberg (DH) parameters of each finger are determined. The figure 1 shows the link coordinates of a single finger used to determine the DH parameters as shown in table II. θ and d are the two joint parameters : joint angle and joint distance, respectively. α and a are the two link parameters : link twist angle and link length, respectively.

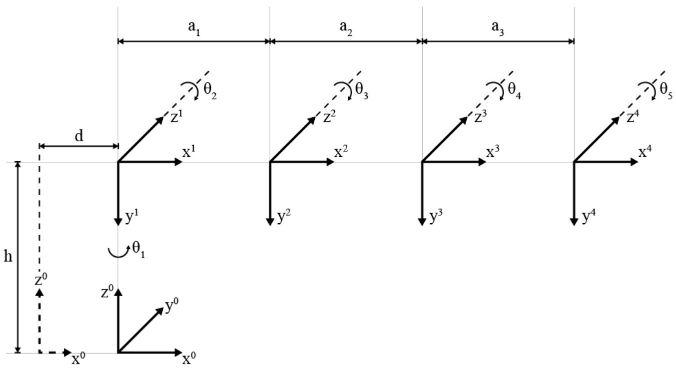


Fig. 1. Link coordinates of a single finger

TABLE II
DH PARAMETERS

θ	d	α	a
θ_1	h	-90	d
θ_2	0	0	a_1
θ_3	0	0	a_2
θ_4	0	0	a_3

θ_1 of the middle finger 1 (Fig:2) is fixed but is kept as a variable in the kinematic equations for uniformity of expressions across all fingers.

C. Torque Equations

Grasping action of each finger is independently controlled by a motor and symmetrically opposable fingers can be rotated from 30° to 110° by the fourth motor. The assumptions [6] considered are :

- The object which is to be grasped is assumed to be cylindrical in shape and placed with its axis perpendicular to the plane in which it is kept.
- The tip of each finger is only making contact with cylinder.
- The plane formed by the intersection of point of contact of finger tip with the cylindrical object is parallel to the circular plane of the cylinder.
- The coefficient of static friction between the fingers and the object is assumed to be the same.
- The transmission system is made up of gears and belt drives and we assume the net transmission ratio from motor to the joint is one.

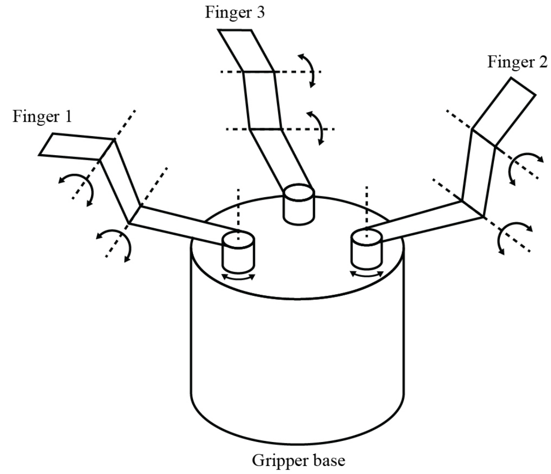


Fig. 2. Schematic of 3 finger gripper

Let force applied by fingers 1,2 and 3 be F_1, F_2, and F_3 respectively as shown in fig 3. γ is the angle between F_1 and xy plane. Then, γ can be written as: $\gamma = -180 + (\alpha + \beta)$

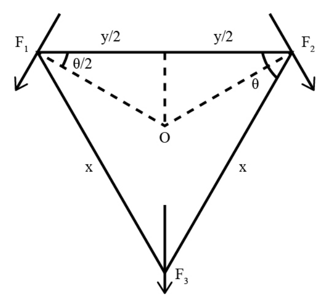


Fig. 3. Force Resolution

where α and β are the angles made by the finger joints with the adjacent links. From figure, $\theta/2$ is found to be

$$\theta/2 = \frac{\cos^{-1}}{2}\left(\frac{y}{2x}\right) \tag{1}$$

Resolving the force along Z axis :

$$\mu \cos\gamma\,(F_1 + F_2 + F_3) = mg + (F_1 + F_2 + F_3)\sin\gamma \tag{2}$$

Here, μ is the coefficient of static friction and m is the mass of payload.

Resolving the force along X and Y axis :

$$\cos\gamma(F_3) = \cos\gamma\,(F_1\cos(90-\theta/2) + F_2\cos(90-\theta/2)) \tag{3}$$

$$F_1\cos\gamma\cos(\theta/2) = F_2\cos\gamma\cos(\theta/2) \tag{4}$$

which implies, $F_1 = F_2$

$$F_1 = F_2 = \frac{F_3}{2\cos(90-\theta/2)} \tag{5}$$

$$F_3 = \frac{mg}{(\sin\gamma + \mu\cos\gamma)(1+\sec(90-\theta/2))} \tag{6}$$

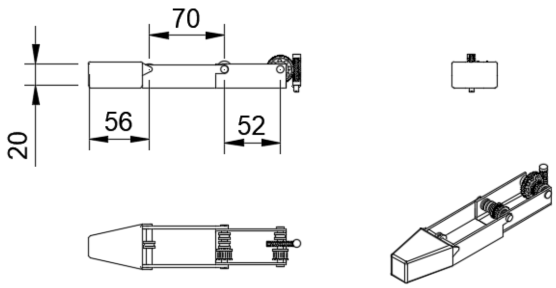


Fig. 4. Dimensions of the finger (in mm

τ_{ik} represents the torque produced at the k^{th} joint of i^{th} finger, where $1 \leq k \leq 2$ and $1 \leq i \leq 3$. The joints are numbered from the tip to the base of the finger.

$$\begin{aligned}\tau_{11} &= \tau_{21} = F_{111} = F_{21} \times l_{21} \\ &= \frac{\mathrm{mg}\, l_{11}}{2\cos(90-\theta/2)(\sin\gamma+\mu\cos\gamma)(1+\sec(90-\theta/2))}\end{aligned} \tag{7}$$

Here l_{ip} represents the link length of p^{th} phalange of finger i, $1 \leq p \leq 3$, where the numbering starts from the tip of the finger to the base.
l_{11}, l_{21} and l_{31} are the length of links of the gripper that are in contact with the object.

$$\text{Torque } \tau_{31} = F_3 \times l_{31} \tag{8}$$

$$= \frac{mgl_{31}}{(\sin\gamma + \mu\cos\gamma)\,(1 + \sec(90 - \theta/2))} \tag{9}$$

Therefore, torque produced at the second joint of finger1, finger2 and finger3 are τ_{12}, τ_{22} and τ_{32} respectively:

$$\begin{aligned}\tau_{12} &= F_1 \times (l_{11} + l_{12}) \\ \tau_{22} &= F_2 \times (l_{21} + l_{22}) \\ \tau_{32} &= F_3 \times (l_{31} + l_{32})\end{aligned} \tag{10}$$

Torque required for driving motor 1, motor 2 and motor 3 are T_1, T_2 and T_3:

$$\begin{aligned}T_1 = T_2 &= \tau_{11} + \tau_{21} \\ &= F_1\,(2l_{11} + l_{12}) \\ &= \frac{mg\,(2l_{11} + l_{12})}{2\cos(90 - \theta/2)\,(\sin\gamma_+\mu\cos\gamma)\,(1 + \sec(90 - \theta/2)}\end{aligned} \tag{11}$$

$$\begin{aligned}T_3 &= \tau_{32} + \tau_{31} \\ &= F_3 \times l_{31} + F_3\,(l_{31} + l_{32}) \\ &= \frac{mg\,(2l_{31} + l_{32})}{(\sin\gamma + \mu\cos\gamma)(1 + \sec(90 - \theta/2))}\end{aligned} \tag{12}$$

Here, $\mu = 0.4$; $l_{11} = l_{21} = l_{31} = 50mm$; $l_{12} = l_{22} = l_{32} = 70mm$ and $l_{13} = l_{23} = l_{33} = 60mm$; $m = 250g$; $\theta/2 = 45°$ and $\gamma = 30°$

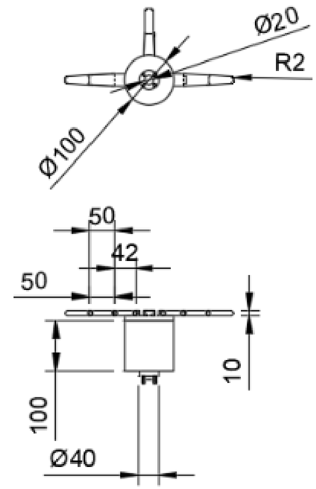


Fig. 5. Design of simplified model for URDF.

$T_3 = 0.52Nm$ and $T_1 = T_2 = 0.204Nm$
For $\omega = 4rad/s$,
Power was found to be $P_3 = 2.08W$ $P_1 = P_2 = 0.816W$.
The obtained values can be seen in the table III

TABLE III
MOTOR PARAMETERS

Motor name	Torque(Nm)	$\omega(rad/s)$	Power(W)
$Motor_1$	0.52	4	2.08
$Motor_2$	0.204	4	0.816
$Motor_3$	0.204	4	0.816

D. Final Design

Based on the dimensions of tool flange of ABB IRB 120, a 3D model of the gripper is created Fig: 5. The final design was made using a 3D modeling software named Fusion360 (See Fig: 4). The final render of the model is shown in Fig: 6

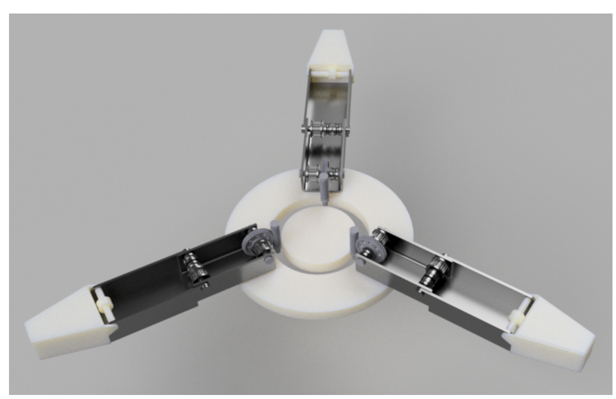


Fig. 6. Render of model in Fusion360

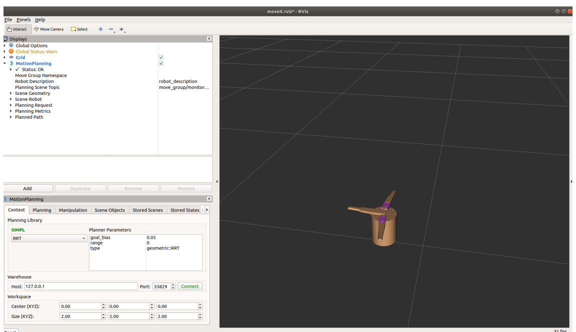
IV. Simulation

The simulation was done in RViz and Gazebo.

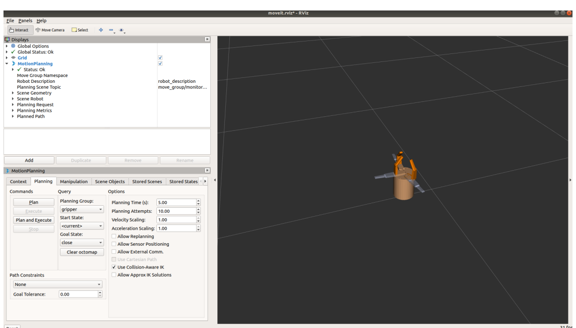
A. Modeling the robot URDF

The Unified Robotic Description Format (URDF) is an XML file format used in ROS to describe all elements of a robot. This is frequently used in ROS for generating joints and for generating the transformation coordinate frames of the required robot. URDF format is needed for visualizing in RViz ,for simulating in Gazebo and for hardware ROS control.

URDF of both models (gripper and gripper attached to ABB) was generated using a plugin ”sw_urdf_exporter” in SolidWorks.



(a)



(b)

Fig. 7. (a) Planning in RViz, (b) Execution in RViz

B. Motion planning of gripper in RViz

RViz is a virtual world visualization tool used for ROS applications. MoveIt! provides us with a plan that the joints have to follow to move an arm from one position to another.

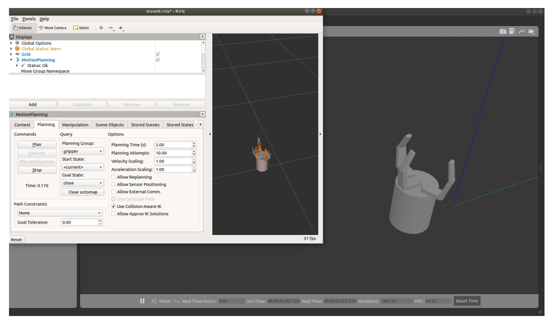
The first step before launching it in a simulation environment is to configure the model. This is done by launching the URDF model in MoveIt! assistant. This creates the configuration and launch files required to use a robot with the MoveIt!, RViz and Gazebo.

The model can be visualised in RViz by creating a launch file. The various poses that were set in Moveit assistant can be planned and executed in RViz using Rapidly-exploring random tree (RRT) planning algorithm available through a plugin. Planning and execution in RViz is as shown in Fig:7.

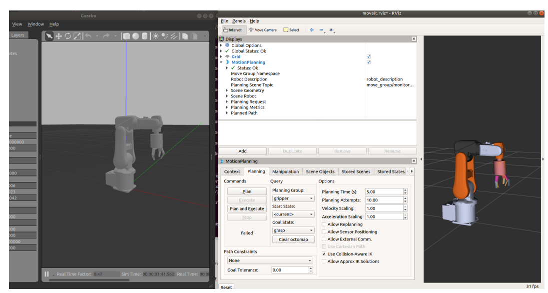
Rapidly exploring Random Tree is a Sampling Based Planning(SBP) algorithm that has been designed for searching paths in high-dimensional spaces. RRTs are constructed by expanding the tree to a randomly-sampled point in the configuration space given that it satisifes the constraints. [7]

C. Simulation in Gazebo

Gazebo is a multirobot simulator for complex indoor and outdoor robotic simulation. The simulation model for the gripper can be created by adding simulation parameters to the updated robot description format. [8] After launching the model in Gazebo, use the move_group command and then launch RViz using the moveit_rviz.launch command. The motion path planned on the RViz can now be achieved on Gazebo i.e. in a real world environment. This can be seen in Fig:8.



(a)



(b)

Fig. 8. (a) Simulation of gripper in gazebo, (b) Simulation of gripper attached to ABB manipulator

V. Conclusion

A three fingered gripper was designed, simulated and implemented in three stages.The design was based on the requirement that gripper needs to compatible with the ABB IRB 120 model. Kinematic modeling was done using forward and inverse kinematics. Then a 3-D model was created in SolidWorks for the purpose of URDF generation. The URDF model was then simulated in Gazebo in integration with RViz for motion planning. A final model that meets the required specifications was created using the software Autodesk Fusion360. The objective of the paper to simulate the gripper in ROS framework was successfully achieved.

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