ARDOP 3.0

1) A Brief History of Ardop

ARDOP (Autonomous Robot Development Open-source Platform) is an open source humanoid robot that serves as an extensive platform for the development of robotic applications. The first generation of ARDOP (Fig1) was completed in the year 2017, this robot was capable of performing object manipulation. It consisted of a DUO MLX camera (a 3D camera), the body was 3D printed using ABS plastic, Pseudo Inverse Jacobian technique was used to perform the inverse kinematics, Convolutional Neural Networks (using CAFFE) was used to implement object recognition using the stereo depth map.

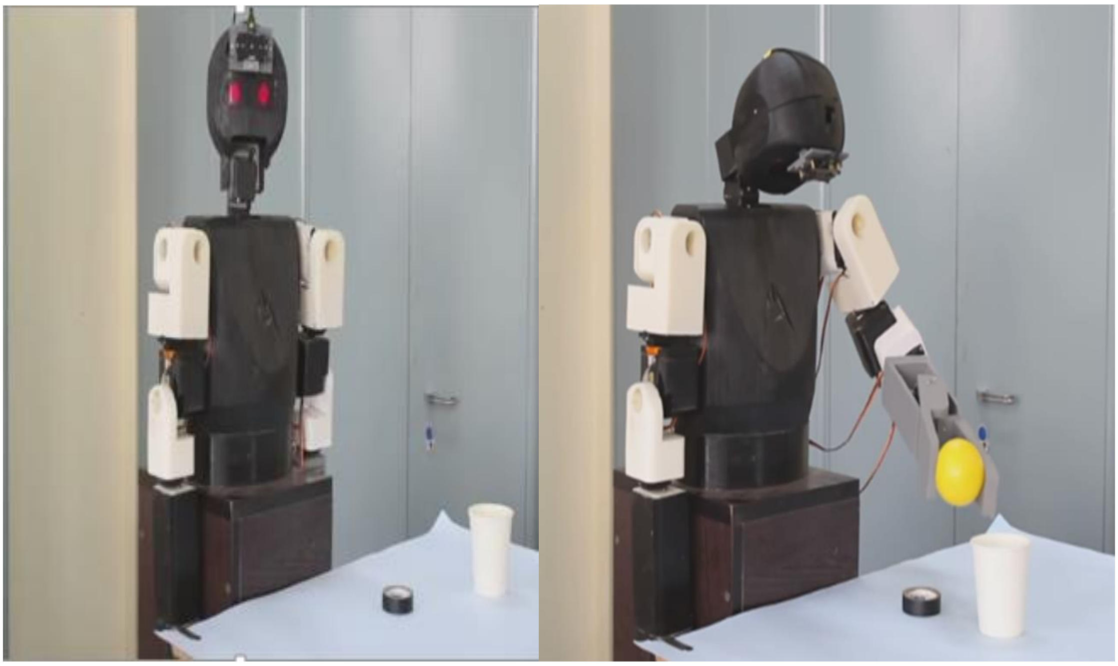


Fig 1: ARDOP1.0

The second generation of ARDOP (Fig2) was started in the year 2017 and completed in May 2018. This time an alternative approach was invoked to perform object manipulation, the arms were redesigned, the vison system consisted of a Kinect camera and YOLO was used for object recognition, a mobile base was setup for the robot with an intention of performing navigation through an indoor environment and simulations were performed in ROS platforms such as Rviz and Gazebo by development of a Moveit package. The robot was completely developed on ROS. URDF (Universal Robot Description File) was developed using SolidWorks and exported to ROS.

Fig2: ARDOP2.0, simulation of the robot can be seen in the background of the image (right)

The third generation of ARDOP was started August 2018 and has been an active member of many presentations and events that were conducted within BMSCE and outside. ARDOP3.0 has been presented in “BMSCE –FIU (Florida International University) association meeting”it was held at IISC on the 30th of July 2018, In this meeting the concepts of ARDOP3.0 and our vison for the project was presented and it had the garnered appreciation of the audience.

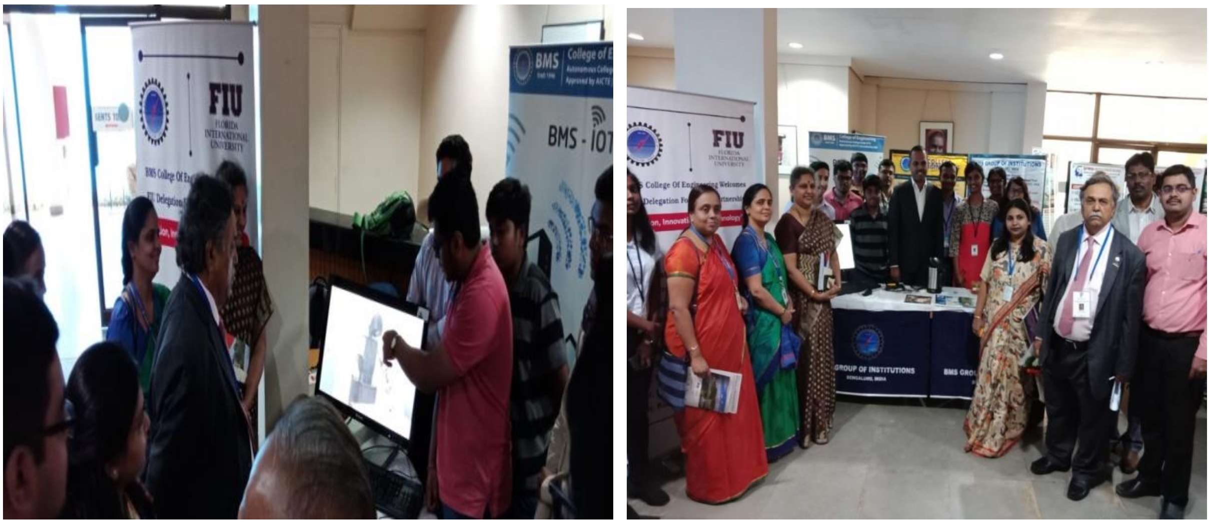


Fig3 : Students and professors of BMSCE, presenting ARDOP3.0 at the BMSCE –FIU (Florida International University) association meeting, and had also interacted with the professors of FIU.

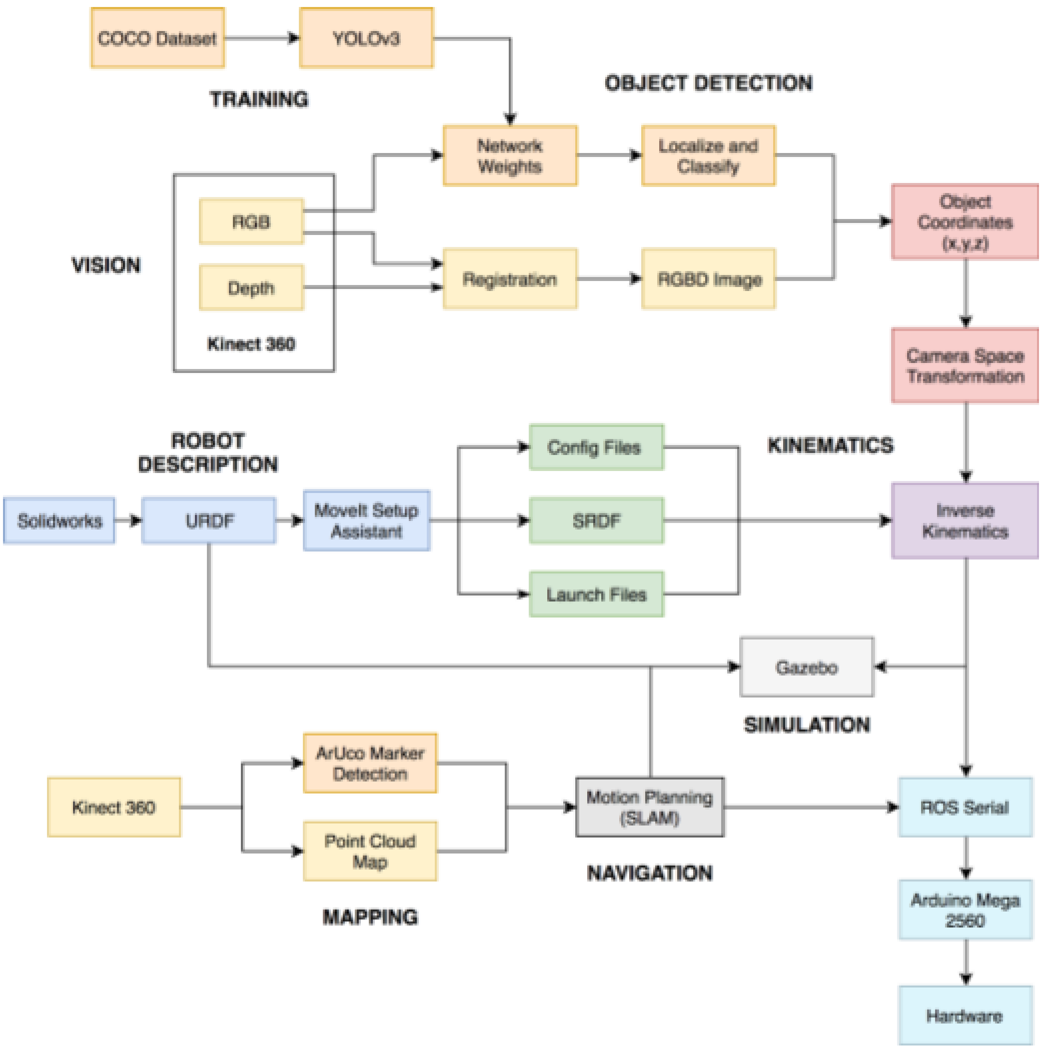
Phase Shift 2018 an annual National Level technical symposium held at BMSCE, was held on the 15th of September and ARDOP3.0 was a part of the Electronics and Communication stall that was put up by the department to exhibit its projects, and department won the best stall exhibition award.

Fig4: Members of the stall and the jury with ARDOP

Fig5: Shrinidhi from ECE departmenet, who is also a developer of ARDOP shakes hand with it

Many committees including NAAC and TEQIP has visited Embedded Systems and Robotics Lab and witnessed the demonstration of ARDOP 3.0. The following report presents a elaborate description on the working and development of ARDOP3.0, its current progress and future prospects.

2) Working Methodology of ARDOP3.0



The problem statement is presented in figure6 ,the robot has to move from the startinng point to the source zone where it has to pick up a object and move towards the destination zone and place it. The working methodology can be described as shown in the block diagram, the 3D camera (kinect) identifies the object and provides that is to be picked and placed, the object is picked by the arm by performing inverse kinematics, and the process of loaclization and navigation is performed using SLAM(simoltaneous locaization and Mapping).

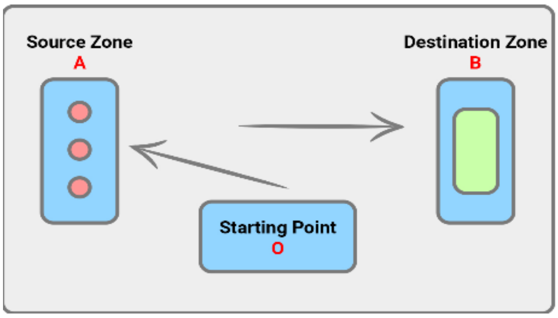


Fig 6: Problem statement of ARDOP3.0

The URDF of the robot was built using solidworks and was exported to ROS, where the simulations have been performed. All the concepts of the robot has been simulated in ROS platforms such as Rviz and Gazebo and has been integrated with the hardware.

3) Design of the Robot

ARDOP3.0 has been designed to overcome few of the issues that were present in the previous generations. The complete robot has been redesigned and a mobile platform was provided for locomotion. The body of the previous generations of ARDOP was 3D printed using ABS plastic, this was weak and brittle in order to overcome this issue we have built the body using sheet metal (Cr). ARDOP consist of 6DOF arms that enable it to grasp objects in different orientations, the arm has been driven by high torque servo motors. The body has been mounted on-top of a mobile chassis, which consist of 3 compartments to house the battery and other circuitry. This is driven by high torque DC motor with Quadrature encoder. The complete robot was designed in Solidworks, taking care of the physical constrains.

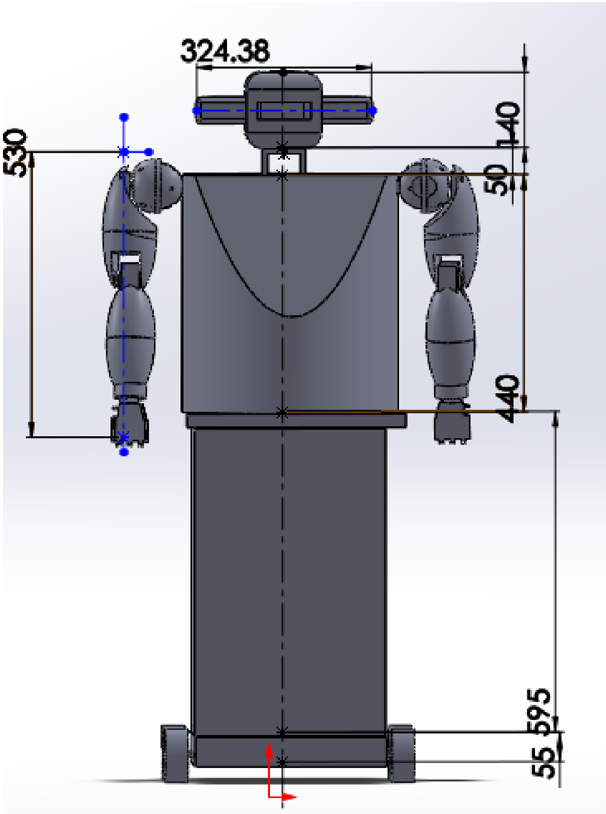


Fig: Solidworks Model of the ARDOP 3.0

- **Mobility Platform:**

The Mobility platform consist of a chassis with 4 wheels, driven using a DC motor of 60Kg-cm torque and a speed of 30rpm with Quadrature encoder. The mobility platform has been built using Aluminium bars and the base is made of wood. The motors are housed in the chassis.

The wheels have been driven by a coupler; it couples the shaft and the wheel. The rotation of the shaft of the motor is transferred to the wheel by means of a coupler.

Advantages:

1) High torque motors are available, which can be driven using on-board DC power supply, reducing complexity in circuit.
2) The motors purchased consists Quadrature encoders that provide a reliable feedback.

Disadvantages:

1) Movement of structure is relatively slow.
2) The movement is not totally stable.

Fig 7: Structure including Chassis to provide Rigidity and Mobility

Fig 8: Wheel used to provide mobility to the structure (Left) and Stepper Motor used to power the Wheel (right)

- **Power distribution and Servo driver Circuit**

The previous generations of ARDOP had been powered using a SMPS it converts the AC supply to regulated and filtered DC supply and can source a maximum of 40A of current at 12V. ARDOP3.0 is mobile robot and hence a SMPS cannot be deployed. A 12V 60Ah , lead acid battery has been used as the source of power for the entire robot. This battery is capable of driving the entire robot which consist 16 servo motors, 4 DC motors and a Kinect.

Lead acid, Lithium ion and polymer, Nickel cadmium batteries, were the options that we had explored. Lead acid type secondary battery has been selected because of it's because of its heavy duty performance and cost effective as compared to other batteries.

Various components of a robot work at different power rating, the DC motors draw a peak of 7A of current at 12V, the servos work between voltage ranging between 5-8.5V and current between 1-3.5A. To satisfy these diverse power requirements a power distribution and Servo driver circuit was built using buck and boost dc converters. These converters have the following specification:

1. Input voltage: 7-40V.
2. Output voltage: 1.2 – 35V, adjusted using on-board potentiometer.
3. Output current:0-8A, adjusted using on-board potentiometer.
4. Output power(max) : 300W

Fig 9: DC-DC buck and boost converter

Advantages:

1) The power distribution circuit is capable of distributing power to each motor at its prescribed rating.
2) They also incorporate safety circuits preventing possible accidents caused due to short circuit.

Disadvantages:

1) The battery is heavy hence the weight of the robot increases.
2) To drive this heavy weight robot high torque motors are necessary these motors are expensive.

Fig 10 : Battery used to provide Power to the circuit

- **Vison:**

Robotic vision refers to capability of perceiving the environment and using this information for execution of different tasks like pick and place, autonomous navigation, object recognition etc. Vision is implemented in order to give the visual feedback to the robot system to achieve the tasks at greater accuracy. The previous generation of ARDOP consisted of a DUO MLX camera, the drawback with this was that the image obtained was a grayscale image. This was overcome using a Kinect camera that provides a RGB image and it is capable of integration YOLO (used for object recognition) has been used.

The Kinect and its constituent components is shown in Fig 11. The working of Kinect is as follows With the help of IR projector the Kinect transmits an IR rays in specific pattern called structured light these rays get reflected when they hit the obstacle these reflected rays is sensed by the IR receiver and from this data with the help of Kinect depth perception it able to estimate the depth in distance of each every pixel in its frame. To calculate the distance it uses ToF (Time of Flight) or structured triangulation in Kinect v3 it uses ToF.

Fig 11: Kinect and it consituent components

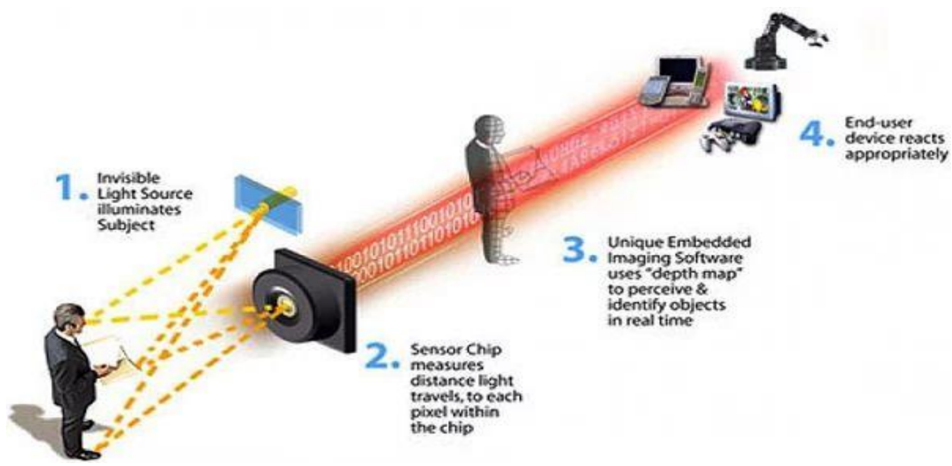


Fig 12: Working of Kinect

Object detection is done using CNN (computer neural networks) i.e. is through deep learning concepts. There are different object detection algorithms available are Single shot detection (SSD) , RetinaNet, You Only Look Once (YOLO).

YOLO object detection method is used because of its higher accuracy than compared to others, YOLO works on neural network with darknet53 architecture and it able detect around 80 classes.

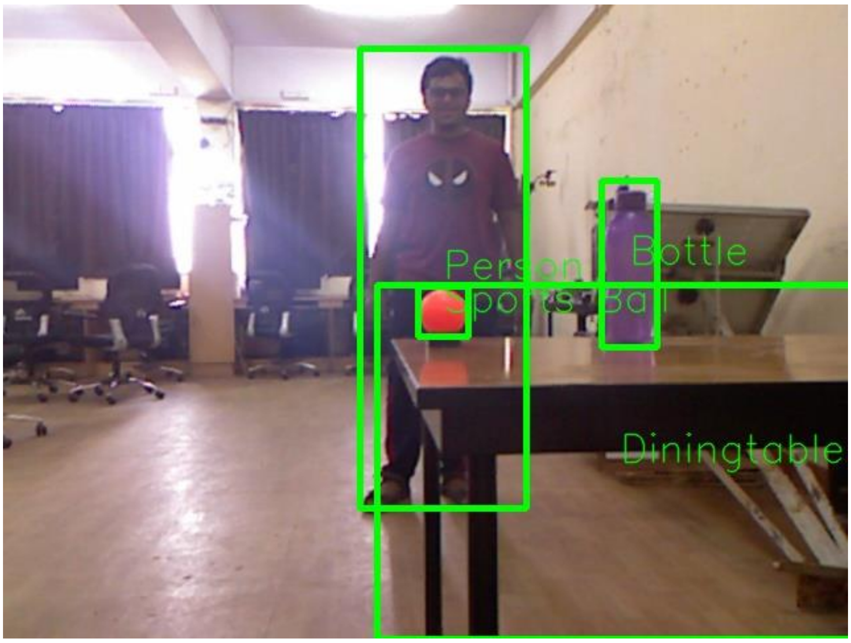


Fig: End image of Kinect detecting different objects in its field of vision

Advantages:

1) Kinect consist of an inbuilt motor, thus the design of the head actuation system is simple.
2) It can be interfaced with ROS.
3) It enables use of features such as skeleton tracking.

Disadvantages:

1) It is heavy, hence high torque motors is to be used in the neck joint.

2) It has a blind spot of 45cm radius, which is within the workspace hence this had to be compensated by increasing the height at which the Kinect was placed.

- **Kinematics of the Robotic Arm:**

Kinematics deals with techniques required to move the robotic arm to a desired position in space. Kinematics can be broadly classified in forward and inverse kinematics. Forward kinematics is used to determine the position and orientation of the end effector in space given the joint angles, inverse kinematics is used to solve the problem of determining the joint angles of the arm, given the end effector position and orientation.

ARDOP currently has one 6DOF arm, a spherical wrist is used to provide the end effector to grasp objects in any possible orientation. The previous generations consisted of arms that were 3D printed these arms were heavy, to overcome this we have built a poppy arm using Balsa Wood, using this technique the weight of the arm(excluding servo weight), has been reduced from 600g to 250g. This also helps to reduce the power required to drive the arms. The motors at the shoulder include high torque servos (35kg-cm), and they have been driven using the servo driver circuit.

The development of kinematics took place in two stages the first stage included simulation of the arm kinematics in ROS platforms such as Rviz and Gazebo and the next stage was to implement it on the hardware by integrating simulation and hardware. Inverse kinematics was also developed using mathematical techniques such as geometry based technique and iterative methods such as Pseudoinverse Jacobian technique.

Simulation

The simulation was started by testing the URDF of the robot that was developed using Solidworks. This model was imported into ROS, and a Moveit Package was built. Moveit consist of IK solvers (Inverse Kinematics) such as KDL(Kinematics and Dynamics Library) , using these libraries the IK was solved. Obstacle avoidance was also employed using collision aware IK. The results of the simulation is shown in Fig 13, Fig 14 and Fig 15.

Rviz is a visualizer and Gazebo is the real world representation of the robot in simulation. The arm is moved to the desired position using the available interactive markers or a python script that passes the coordinates of the final destination can be used. Once the coordinates and the orientation of the end effector is known KDL is used to develop the IK and trajectory plan. The execution of the visualizer (Rviz) can be seen in the real world model (Gazebo). Fig 14 demonstrates the simulation results.

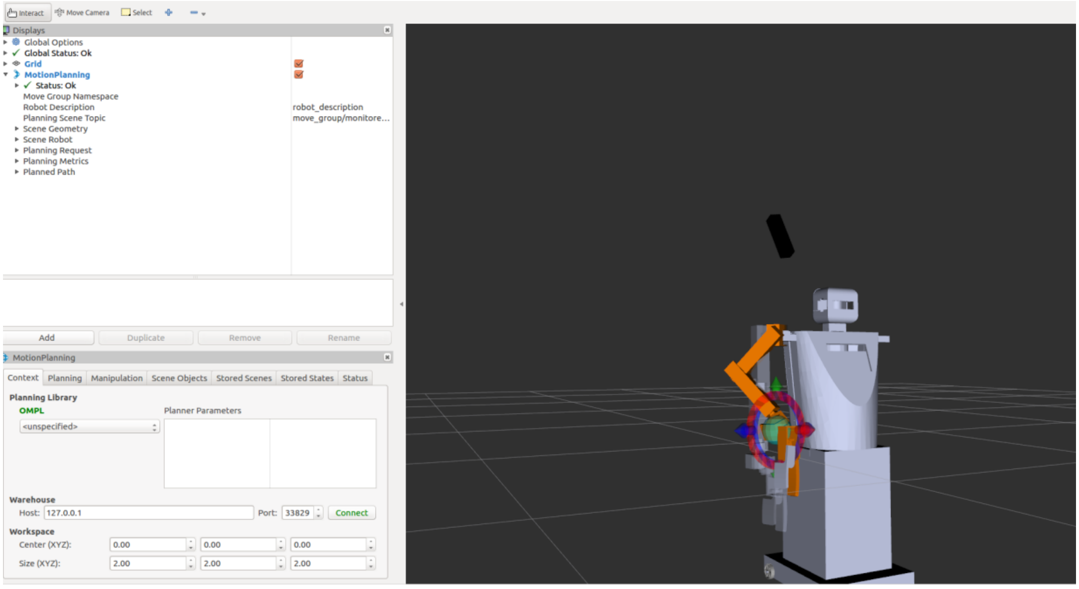


Fig13: The destination and orientation of end effector has been set using interactive markers

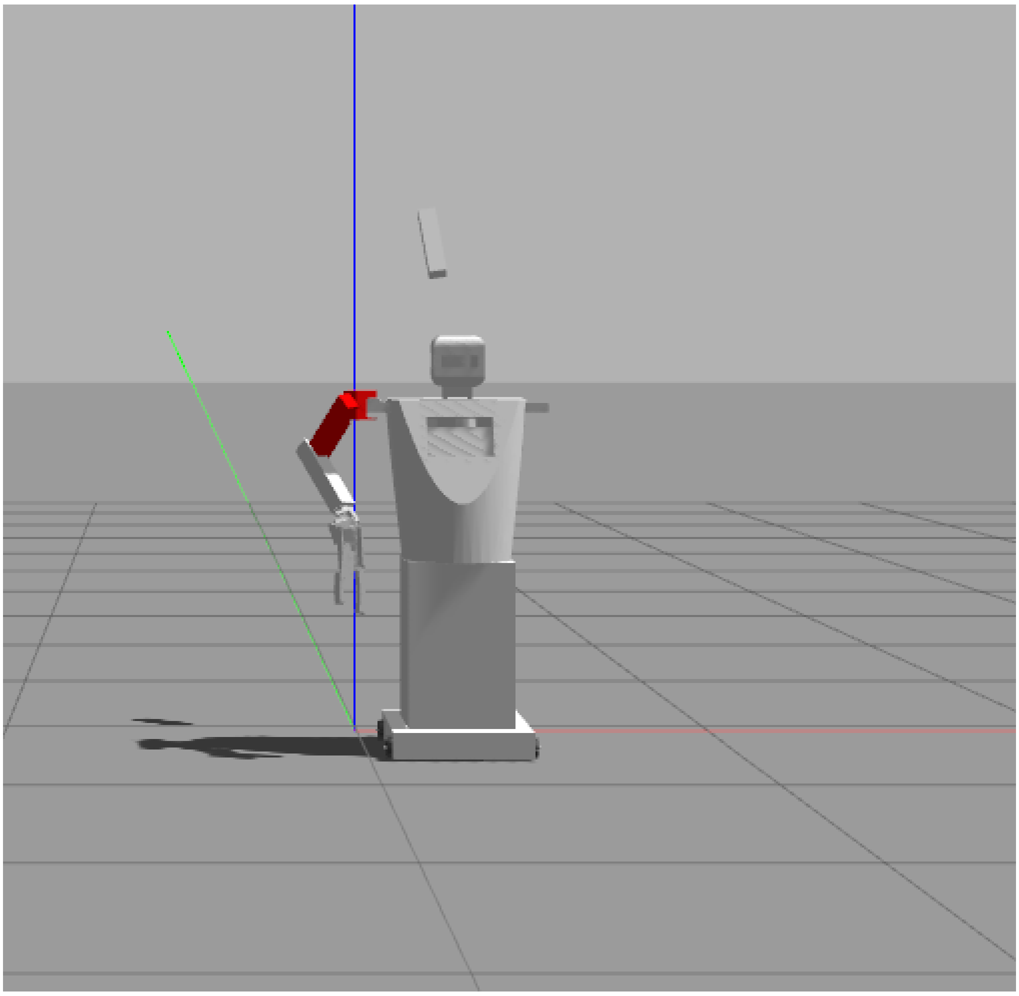


Fig14: The plan visualizsed in Rviz is being executed in the simulation and end effector is movd to desired poisiton.

The robot is capable of avoiding obstacles within the workspace of the arm; this has been simulated in Rviz and a collision aware IK has been developed. The results of obstacle avoidance is shown in figure 15.

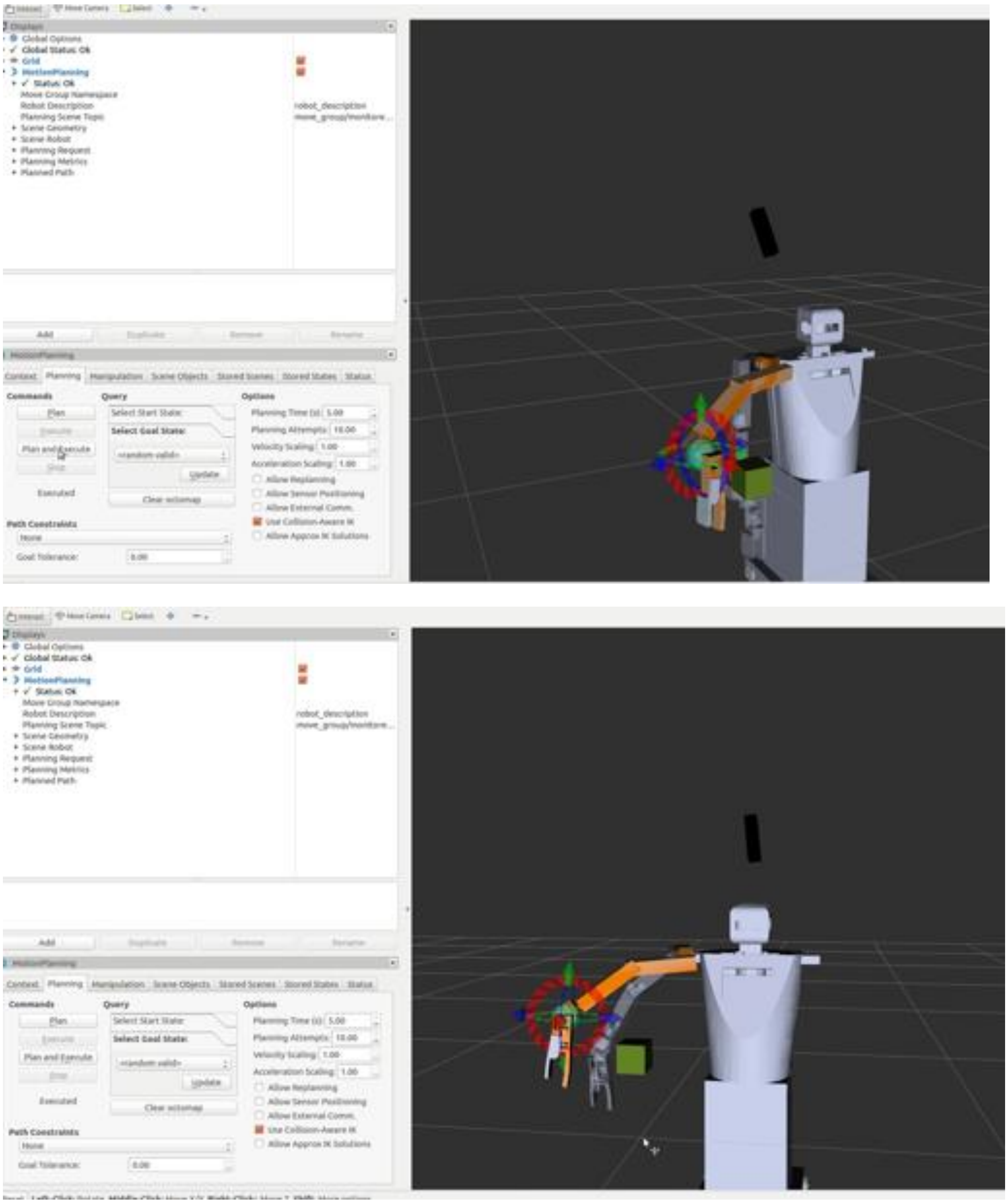


Fig 15: In both of the above figures collision avoidance is dmonstraed the IK is genreated and the trajectory is planned such that the obstacle (Cube) , is avoided.

Hardware Implementation

The Denavit Hartenberg matrix is the conventional technique that is used to obtain a matrix that describes the forward kinematics of the arm. This technique has been used to develop the forward kinematics for the ARDOP arm. Inverse Kinematics has been developed in 3 unique ways.

1) Integration ROS of simulation and hardware.
2) Geometry based solution.
3) Pseudo-Inverse Jacobian technique.

Trajectory planning has been developed using 2 techniques

1) Integration ROS of simulation and hardware.
2) Development of cubic trajectory with via point.

The hardware and ROS has been integrated by using Rosserial, here simulation has been run in Ros and executed in gazebo, the joint angles are published by a python script and is subscribed by the Arduino and these angles are passed to the servos.

The geometry based solution involves viewing of the position of arm the end effector from various frames of reference and developing a general equation using geometrical techniques. Once the formulas are obtained a python script was written which was capable of solving the IK.

Pseudoinverse Jacobian technique is an iterative method to solving the IK, here a Jacobian matrix was derived and using the basic analytical equations and a pseudoinverse Jacobian matrix was obtained and was used to solve the IK.

The trajectory plan was developed so that the robot picks up the object without colliding with any of the obstacles. Fig 16 demonstrates the hardware implementation of the inverse kinematics and trajectory planning for the pick and place operation of a ball.

Fig 16: Hardware implementation of the IK to pick and place the ball at predefined locations, the trajectory is planned at such that the obstacle (table) is avoided.

Advantages:

1) Due to the reduction in weight, the motors source less current and are less prone to damages and burn outs.
2) As the torque requirements of the arm are well within the prescribed torque of the arm, a higher accuracy is obtained.

Disadvantages:

1) A 3D printed arm is visually more appealing than an arm constructed using balsa.
2) The arm is not brake proof and.
3) The end effector joint is not stable and vibrates during motion, this is because the balsa is soft and a strong housing of the end effector is difficult.

Future Work:

The device Kinect need to be mounted on the head part of the ARDOP for vision recognition and navigation. It needs to be programmed to identify the objects that we need the ARDOP to pick and place in the location that the user needs. The ARDOP 3.0 has still one hand. Another hand needs to be produced and attached. At the same time the stability of the movement of chassis need to be corrected by use of Gyroscope in the apparatus. The entire control of Hardware and Vision needs to be integrated by using ROS for best results and one central control system.

All the cons that have been stated above need to be corrected to maximum extent possible for smooth working of the ARDOP 3.0.