Design Fabrication and Trajectory Planning for Mobile Manipulators

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***Abstract*—Cooperative mobile manipulation is an important capability to extend in the domain of robotic applications. The novel feature enriched by the combination of mobility with manipulators is crucial for applications, ranging from material manipulation task to planetary exploration. The benefits include more workspace, reconfigurability, enhanced disturbance rejection capability of various holonomic and nonholonomic constraints like kinematic and dynamic redundancy. Moreover, cooperative manipulation would lead to powerful dynamic coupling and requires mild motion coordination. Failure to study these effects can cause extreme internal forces and high energy consumption, and even destabilize the system.To deal with these entailed issues, we present a dynamic control algorithm for a robot consisting of multiple nonholonomic wheeled mobile manipulators capable of cooperatively moving the object. The nonholonomic wheeled mobile manipulator consists of a 2DOF manipulator arm mounted on a mobile base. In this algorithm, the high level controller deals with motion, force control of the object, at the same time distributes the motion, force task into individual agents by grasp description matrix.**

Keywords—Cooperative Mobile Robot, Nonholonomic Wheeled Robot, 2DOF Manipulator Arm

I. INTRODUCTION

Generally Manipulator are fixed and work environment is constrained for the application. To do heavy and complex task cooperation two or more manipulators are used. Mainly Manipulators are used in Automobile Industry, Nuclear power plant, Furnace Casting Industry and Automation Industries. To increase work space more scientists develop a mobile Manipulator, which can move to places and do muliple tasks. Furthermore Mobile cooperative manipulator plays vital role in complex and lengthy object transportation, lifting and assembly. Two mobile manipulator joined together to do a task involves lot of complex activity in kinematics, dynamics and cooperation. Manipulation is perhaps the most important task of robotic system, so the extension of this in multi-robot systems naturally has been one of the important goals in cooperative robots. There are many pertained issues to be considered in this process like synchronization of the subsystems, control of the applied forces and motion planning.

The mobile manipulator system has its origin in the laboratory and then later come to the battle field and daily life.

The PackBot EOD, developed by iRobot Corporation, can be rapidly deployed as mobile bomb disposal units. The weight of these kind of robot is less than 24 kilograms fully loaded, and can be hand carried and deployed by a single operator. Scholars from University of Massachusetts Amherst constructed a mobile manipulator hardware platform with redundant kinematic degrees of freedom, a comprehensive sensor suite, and significant end-effector capabilities for manipulation. In recent years, mobile manipulation is getting more attention in the field of space exploration [9]. Future space robots play a critical role in collecting, distributing and maintaining components in extra-terrestrial environments.

The advantage of a mobile manipulator is not only the increased workspace of the robot but also the capability to place itself in a position that provides a collision free environment for the manipulator. The complexity of the manipulation task is increased due to the additional degrees of freedom and uncertainty in sensors and actuators. These challenges attract more researchers in the mobile manipulation field. The state of the art of mobile manipulation has been advanced in recent years. Some of the most advanced state of the art mobile manipulators like PR2, Justin, HRP2, HERB and ARMAR are able to perform complex manipulation, grasping and navigation tasks[9].

At this level, the system could be composed of a homogenous or heterogeneous set of robots of certain characteristics. Research themes in this domain that have been particularly well studied include multi-robot path planning, traffic control, formation generation, and formation keeping. Most of these issues are now fairly well understood, although demonstration of these techniques in physical multi-robot teams (rather than in simulation) has been limited. The promise of collaborative robotic system has been fulfilled in support of missions pertaining to national defense, homeland security, and environmental monitoring.

II. NON HOLONOMIC MOBILE ROBOT

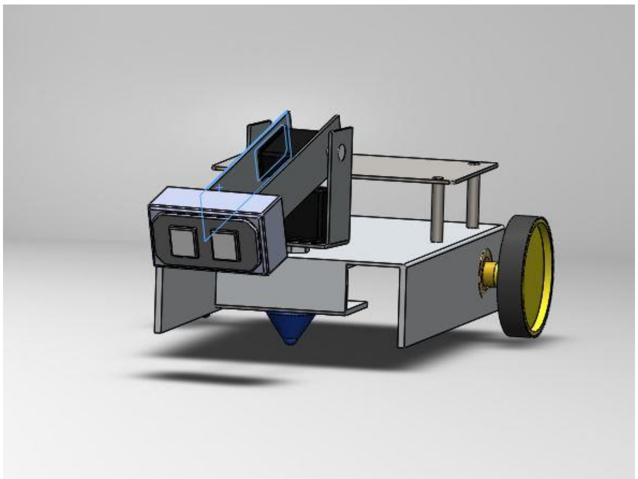


Fig. 1. 2DOF Mobile Robot.

In consideration to interact with a 2 DOF Nonhlonomic Mobile robot attached with magnetic gripper the Robot is controlled by Atmega16 microcontroller with Bluetooth interface for mobile robot. Object is identified using vision camera and processing of image is done using Matlab software and makes mobile robot to perform the task.

III. DEVICE KINEMATICS

Kinematics is the study of motion without regard to the force which causes it. From kinematics we can know the position. The kinematics of manipulator involves the study of geometric and time based properties of the motion, and how various links of the manipulator moves with respect one another.

A. Denavit and Hartenberg Matrix

Denavit and Hartenberg proposed a matrix method of systematically assigning coordinate systems to each link of an articulated chain.

$$A_{i-1}^{1}=\begin{bmatrix} cos\theta_i & -sin\theta_i cos\alpha_i & sin\theta_i sin\alpha_i & a_i cos\theta_i \\ sin\theta_i & cos\theta_i cos\alpha_i & -cos\theta_i sin\alpha_i & a_i sin\theta_i \\ 0 & sin\alpha_i & cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

TABLE 1. DH CONVENTION OF 2 AXES RR MANIPULATOR

Joint	θ	d	a	α
1	θ_1	0	L_1	0
2	θ_2	0	L_2	0

$$A_1=\begin{bmatrix} \boldsymbol{C_1} & \boldsymbol{-S_1} & \boldsymbol{0} & \boldsymbol{C_1L_1} \\ \boldsymbol{S_1} & \boldsymbol{C_1} & \boldsymbol{0} & \boldsymbol{S_1L_1} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{1} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{1} \end{bmatrix} \quad (2)$$

$$A_2=\begin{bmatrix} C_2 & -S_2 & 0 & C_2L_2 \\ S_2 & C_2 & 0 & S_2L_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

$$H=\begin{bmatrix} n_x & o_x & a_x & P_x \\ n_y & o_y & a_y & P_y \\ n_z & o_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

$$Px = L_2 (C_1C_2 – S_1S_2) + L_1C_1 \quad (5)$$

$$Py = L_2 (S_1C_2 + C_1S_2) + L_1S_1 \quad (6)$$

$$Pz = 0 \quad (7)$$

B. Direct Kinematics

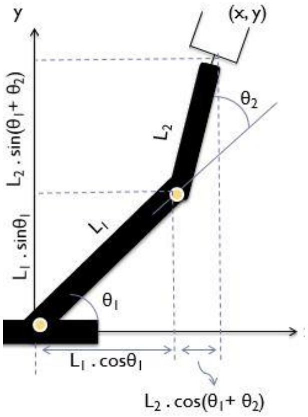


Fig. 2. Two DOF Planar Robot.

$$X=L_1 .cos\theta_1 + L_2.cos (\theta_1+\theta_2) \quad (10)$$

$$Y=L_1 .cos\theta_2 +L_2 .sin (\theta_1+\theta_2) \quad (11)$$

C. Inverse Kinematics

$$tan\alpha = \frac{L_1 sin\theta_2}{L_1+L_2 cos\theta_2} \quad (12)$$

$$\tan\beta = \frac{y}{x} \quad (13)$$

$$\tan\theta_1 = \frac{Y[L_1+L_2\cos\theta_2]-XL_2\sin\theta_2}{X[L_1+L_2\cos\theta_2]+YL_2\sin\theta_2} \quad (14)$$

D. Mobile Robot Position

Throughout this derivation we model the robot as a rigid body on wheels, operating on a horizontal plane. The total dimensionality of this robot chassis on the plane is three, two for position in the plane and one for orientation along the vertical axis, which is orthogonal to the plane. Of course, there are additional degrees of freedom and flexibility due to the wheel axles, wheel steering joints, and wheel castor joints.

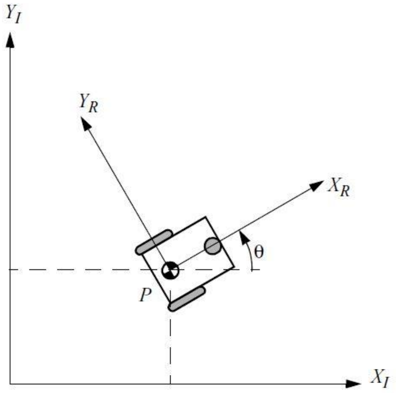


Fig. 3. Global and Local Reference Plane.

I – Global reference plane

R – Local reference plane

$$\xi_I = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix} \quad (12)$$

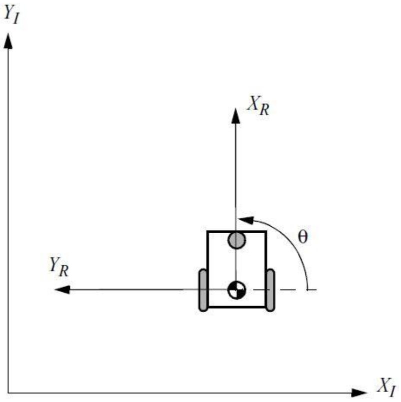


Fig. 4. Mobile Robot Aligned with Global Axis.

$$R(\theta) = \begin{bmatrix} cos\theta & sin\theta & 0 \\ -sin\theta & cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (13)$$

$$\xi_R = R(\tfrac{\pi}{2})\xi_I \quad (14)$$

$$R\ (\tfrac{\pi}{2}) = \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (15)$$

IV. MOBILE ROBOT FORWARD KINEMATICS

This differential drive robot has two wheels, each with diameter r . Given a point p centred between the two drive wheels, each wheel is a distance l from p. Given r, l, θ, and the spinning speed of each wheelφ_3, and φ_2, a forward kinematic model would predict the robot's overall speed in the global reference frame

$$\xi_I = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = f\ (l, r, \theta, \dot{\varphi}_1, \dot{\varphi}_2). \quad (16)$$

$$\omega_1 = \frac{r\dot{\varphi}1}{2l} \quad (17)$$

The same calculation applies to the left wheel, with the exception that forward spin results in clockwise rotation at point p

$$\omega_2 = \frac{-r\dot{\varphi}2}{2l} \quad (18)$$

Combining these individual formulas yields a kinematic model for the differential-drive example robot

$$\dot{\xi}_I = R(\theta)^{-1} \begin{bmatrix} \frac{r\dot{\varphi}1}{2} & + & \frac{r\dot{\varphi}2}{2} \\ & 0 & \\ \frac{r\dot{\varphi}1}{2l} & + & \frac{r\dot{\varphi}2}{2l} \end{bmatrix} \quad (19)$$

We can now use this kinematic model in an example. However, we must first compute $R(\theta)^{-1}$. In general, calculating the inverse of a matrix may be challenging. In this case, however, it is easy because it is simply a transform ξ_R from ξ_I to rather than vice versa

$$R(\theta)^{-1} = \begin{bmatrix} cos\theta & -sin\theta & 0 \\ sin\theta & cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (20)$$

V. CASTOR WHEEL KINEMATICS

The castor wheel, the rolling constraint is identical equation because the offset axis plays no role during motion that is aligned with the wheel plane

$$[\sin(\alpha+\beta) - \cos(\alpha+\beta)(-l)cos\beta]R(\theta)\dot{\xi}_I\text{-}r\dot{\varphi} = 0 \quad (21)$$

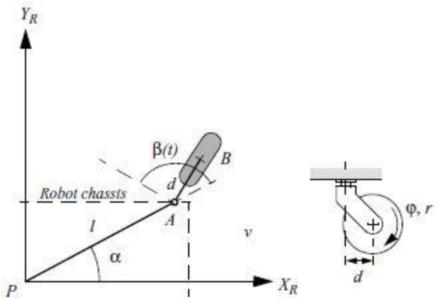


Fig. 5. Castor Wheel Parameters.

$$[\cos(\alpha+\beta)\ si\,n(\alpha+\beta)\ d + lsin\beta]R(\theta)\dot{\xi}_I + d\dot{\beta} = 0. \quad (22)$$

VI. SIMULATION IN MATLAB ROBOTIC TOOLBOX

The code shown below is used to generate the graphical plotting of manipulator using MATLAB2015 robotic toolbox 9.8

```
L1=Link()
L1 =  theta=q, d=           0, a=           0, alpha=           0 (R,stdDH)
L1=Link('d',0,'a',7,'alpha',0);
L2=Link('d',0,'a',13,'alpha',0);
```

```
bot1=SerialLink([L1 L2]);
robot (2 axis, RR, stdDH)


grav =    0  base = 1  0  0  0   tool =  1  0  0  0
          0           0  1  0  0            0  1  0  0
       9.81           0  0  1  0            0  0  1  0
                      0  0  0  1            0  0  0  1
 bot1.fkine([deg2rad(45) deg2rad(0)])
```

Plotting of 2DOF RR manipulator for different joint angles using the DH convention as shown in (Figure5)

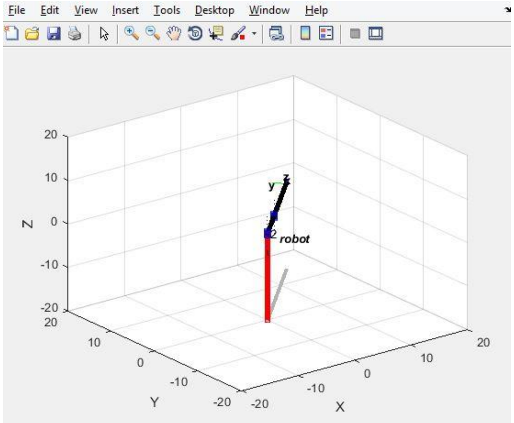
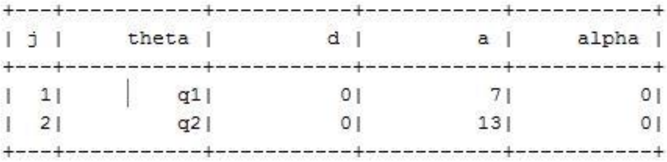


Fig. 6.Zero Angle Configuration.



```
+---+-----------+-----------+-----------+-----------+
| j |     theta |         d |         a |     alpha |
+---+-----------+-----------+-----------+-----------+
|  1|         q1|          0|          7|          0|
|  2|         q2|          0|         13|          0|
+---+-----------+-----------+-----------+-----------+
```

Fig. 5. DH Parameter using Matlab Toolbox.

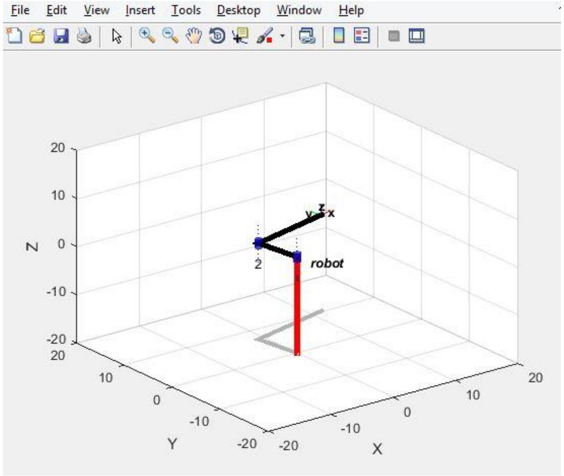


Fig. 7. Configuration with degrees.

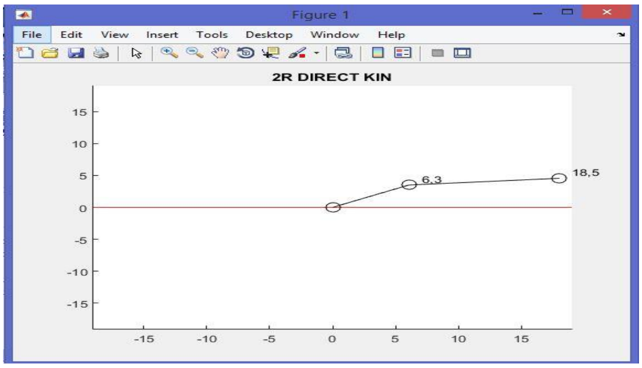


Fig. 8. End Position of given arm FK.

VI. TORQUE CALCULATION

Torque, moment or moment of force is the tendency of a force to rotate an object about an axis. Just as a force is a push or a pull, a torque can be thought of as a twist to an object. Mathematically, torque is defined as the cross product of the lever-arm distance and force, which tends to produce rotation.

The torque requirement of each lifting actuator can be find out by multiplying downward force times the linkage lengths. Centre of mass of each linkage is assumed to be Length/2.

TABLE 1.MANIPULATOR ARM LENGTH

1	Length between J1 and J2	70mm
2	Length between J2 and J3	130mm
3	Length between J3 and Payload	55mm

TABLE 2.ARM AND MOTOR WEIGHT

1	Weight of Link 1	0.052(kg)
2	Weight of joint 1	0.055(kg)
3	Weight of link 2	0.112(kg)
4	Weight of joint 2	0.059(kg)
5	Weight of End Effector	0.150(kg)
6	Weight of Payload	0.080(kg)

TABLE 3. TORQUE REQUIREMENT

Torque at J2	4.564 kg-cm
Torque at J3	9.795 kg-cm

Form above torque calculation servo motor for robot arm are selected as

TABLE 4. SERVO MOTOR SPECIFICATION

Servo Motor for robot Arm	6kg-cm Plastic Gear of 5.5v (for link 1) 10kg-cm Metal Gear of 9.0v (for link 2)

VII. MACHINE VISION

Machine vision is the technology and methods used to provide imaging-based automatic inspection and analysis for applications such as automatic verification, process control, and robot guidance in industry.2D machine vision deals with image analysis

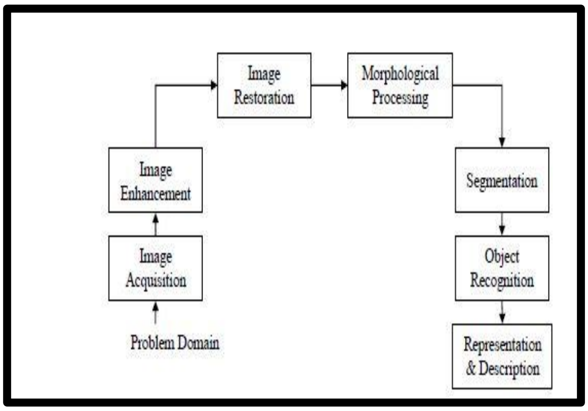


Fig. 9. Stages in Image Processing.

A. *Image acquisition*

The first stage of any vision system is the image acquisition stage. After obtaining image, various processing methods can be applied to the image to perform different vision tasks required. Though, if the image has not been acquired satisfactorily then the intended tasks may not be possible, even with the aid of some form of image enhancement.

Image Acquisition Toolbox enables us to acquire images and video from vision cameras and frame grabbers directly into MATLAB and Simulink. We can detect hardware in plug and configure hardware properties. Advanced workflows let us trigger acquisition while processing in-the-loop, perform background acquisition.

B. *Image enhancement*

It is performed to remove unwanted clutter or noise from an image. Process of adjusting digital images so that the results are more suitable for display or further analysis. Technique used to improve the quality of an image and Enhance Information. An RGB colour image is an M x N x 3 array of color pixels, where each color pixel is a set of three corresponding to the red, green, blue components of an RGB image at specified location. The number of bits used to represent the pixel values determines the bit depth of an RGB image is said to be 24 bits depth.

C. *Morphology*

Binary images may contain numerous imperfections. In particular, the binary regions formed by simple thresholding are distorted by noise and texture. Morphological image processing pursues the goals of removing these faulty image by accounting for the form and structure of the image. These techniques can be extended to grey scale images. After applying suitable morphological operator the resultant image will be free from the noises

D. *Image segmentation*

Image segmentation is the process of partitioning an image into parts or regions. This division into parts is often based on the quality of the pixels in the image. For example, one way to find regions in an image is to look for irregular discontinuities in pixel values, which typically indicate edges. These edges can define regions. One more method is to divide the image into regions based on color values

E. *Object detection and recognition*

Object detection is the identification of an object in an image or video. Computer Vision System Toolbox supports various methods to object detection, includes template matching, blob analysis, and the Viola-Jones algorithm. Template matching uses a small image, or template, to find matching regions in a larger image. Blob analysis uses segmentation and blob properties to identify objects of interest. The Viola-Jones algorithm uses Haar-like features and a cascade of classifiers to identify pretrained objects, including faces, noses, eyes, and other body parts. You can also train a custom classifier.

VI. CONCLUSION AND FUTURE WORK

Non holonomic constraints mobile robot direct and indirect kinematics are understood from various journals for DH and Jacobian method. Modelled a mobile manipulator in SolidWorks Software. Forward and inverse kinematics of mobile manipulator and 2DOF RR manipulator is derived. MATLAB code has developed to find joint angle and end effector position. Torque is calculated to find joint torque and selection of servo motors.

Future works involves modeling a high level controller for cooperation task for mobile manipulator.

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