Kinematic Analysis Of Manipulator Arm For Cutting Of Hazardous Material Using Abrasive Water Jet.

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Abstract

Remotely operated vehicles (ROV) are found to be of great utility in military application. ROVs have been developed to deal with Improvised Explosive devices (IEDs). IEDs are small in size and has limited weight which can be rendered safe by disturbing the circuitry of these small bombs. However it cannot handle large size of explosive stores like bombs dropped from aircraft. Unexploded explosives becomes dangerous to handle and poses threat to nearby area i.e. personnel and equipment. In order to obviate the danger to human life in disposing the unexploded, suspected bombs an Unmanned Ground Vehicle (UGV) is being developed. This UGV will be used to meet the various requirements involved in diffusing and disposing an unexploded bomb. A manipulator arm is being developed and integrated on the vehicle to undertake defusing operation and safe disposal of bombs. The manipulator arm has been designed to hold and handle the nozzle used to impinge abrasive jet on the bomb. This arm will have adequate degrees of freedom to move and access the bombs from various angles. This manipulator will also be remotely controlled. A detail kinematic analysis of the manipulator arm has been carried out to approach the bomb from various angles. This arm is designed for cutting the bomb surface of various radius and lying in different orientation.

Keywords:ROV,Manipulator, Direct kinematics, DH parameters, Work Volume

1. Introduction

Worldwide more and more tons of war zone explosives, terrorist explosive devices and chemical weapons are being found on land and under water. The opening up and deactivation of these bombs, grenades and mines, and also the cutting up and apportioning of solid rocket propellants, place ever higher requirements on the safety of the bomb technicians.Unexploded Ordnance (UXO) becomes dangerous to handle and poses threat to nearby area i.e. personnel and equipment. Till date disposal of these unexploded Ordnance or bombs is being undertaken manually by armed forces. In order to obviate the danger to human life in disposing the unexploded, suspected bombs it is desired to use Unmanned Ground Vehicle (UGV) for handling these hazardous material. A remotely operated UGV basically a 'Skid Steer Vehicle' is being developed to meet the various requirements involved in diffusing and disposing a unexploded bomb. The main arm of skid steer will be used for handling the UXO. A secondary arm or manipulator needs to be developed and integrated on the vehicle to undertake diffusing operation and safe disposal of bomb.

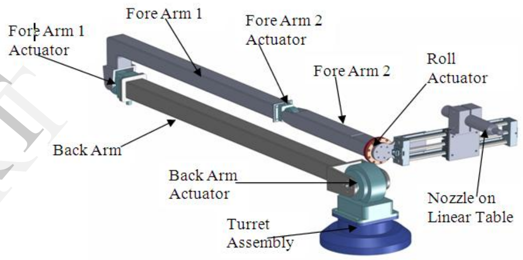


Figure 1 Manipulator Arm Assembly

The manipulator needs to be developed to hold and handle the nozzle used to impinge abrasive jet on the explosive. This arm needs to have adequate degrees of freedom to move and access the explosive from various angles. This manipulator will also be remotely controlled.

The articulated manipulator arm with 5 rotary joint and one prismatic joint has been used for different jointsrefer figure 1. Matlab 6.1 has been used for simulation for Direct kinematics. Direct kinematics is a method to compute the position and orientation of the manipulator's end-effector relative to the base of the manipulator as a function of the joint variables. The position of end-effector has been found by transformation matrix from base to the end effector by the use of D- H parameters, using symbolic computation of Matlab. The work space of the manipulator arm has been generated.

2.Manipulator Design

For cutting an unexploded bomb lying in different orientation, manipulator has to be designed keeping various paths to be traced by the manipulator as per the requirement.Following cases of bomb orientation are considered :-

i. Unexploded bomb is lying on the surface.
ii. Nose of the unexploded bomb is buried in the soil and only tail portion is visible.
iii. Entire unexploded bomb is buried under the soil.

After giving a thought to various paths that manipulator will have to traverse on the bomb surface. We have finalized the concept of manipulator as depicted in fig 2. θ_1 is the angle of rotation of the turret. The back arm is connected to turret and back arm will have pitch movement θ_2. Further forearm 1 is connected to back arm and will have pitch movement at θ_3. Forearm 2 is connected to forearm 1 at θ_4 and will have pitch movement. At the other end of forearm 2 we have rotational movement at θ_5 where a linear table with nozzle is attached.

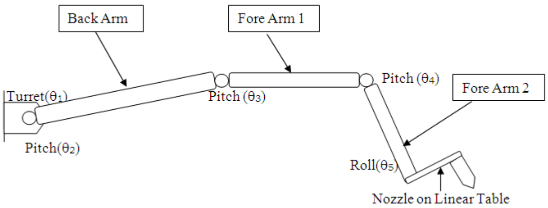


Figure 2 Schematic of Manipulator Arm

For cutting a circular template on bomb surface we have to tilt the forearm 2 at θ_4 by 90 ° and then give roll at θ_5 so that nozzle traces a circular path on the bomb surface. Rotary actuators are selected for actuation of all joints. Torque requirement of motors were calculated considering the payload and the link weights refer figure 3. Since the end effector nozzle has to follow various paths for cutting with precision, design of arm was stiffness based and deflection of the links has been kept within the acceptable limits. [4] For metal cutting application the system with high stiffness and low weight provide better accuracy. Cross sections of the links were finalized keeping the stiffness requirement in view.Bending moment is calculated with the loads as shown in figure 3. Bending moment was calculated as 282.75 N-m for back arm, 102.750 N-m for forearm 1 and 23.25 N-m for forearm 2. FE analysis of the links was carried out using abaqus CAE 6.10-1. Deflection was found to be 0.0858 mm for back arm, 0.184 mm for forearm 1 and 0.0139 mm for forearm 2.

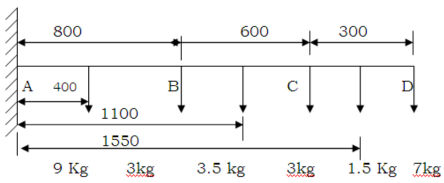
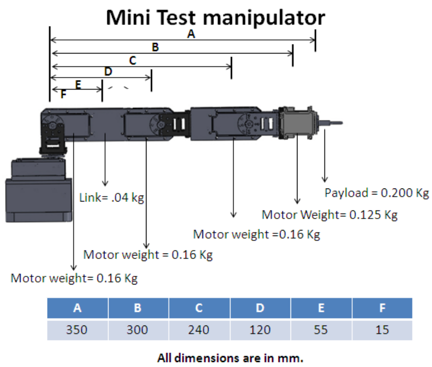


Figure-3Load Diagram for arm with link weights and actuator weight



2.1 Realisation of prototype Manipulator

Figure 4 Schematic of mini Manipulator

A Scale down prototype of manipulator arm was modeled for realization refer figure 4. The aim of developing a prototype arm was to prove the concept of various approaches for cutting a bomb. Motors were selected based on the torque requirement adequate to sustain the weight of the actuator, payload and the mounting attachment.

Dynamixel actuators MX-106 and RX-64 are used for prototype manipulator arm. The actuators are supplied with standard attachment frames and horns for forming various links of the arm. In spite of the compactsize, it generates relatively big Torque by way of the efficient speed reduction. It can read the current position and speed. It is easy to wire since it is connected with Daisy chain. The main body is made of engineering plastic to withstand against strong external force. Since a bearing is used at the last axis of the gear, the amount of efficiency reduction is minimal even if strong external force is applied to the axis.

3. <u>Manipulator Kinematics</u>

In this section the articulated manipulator arm with 5 rotary joints has been simulated for different joint variables. Matlab 6.1 has been used for simulation for Direct kinematics. Direct kinematics is a method to compute the position and orientation of the manipulator's end-effector relative to the base of the manipulator as a function of the joint variables. The position of end-effector has been found by transformation matrix from base to the end effector by the use of D- H parameters, using symbolic computation of Matlab. The work space of the manipulator arm has been generated.

3.1 Denavit-Hartenberg (D-H) Parameters for manipulatorarm

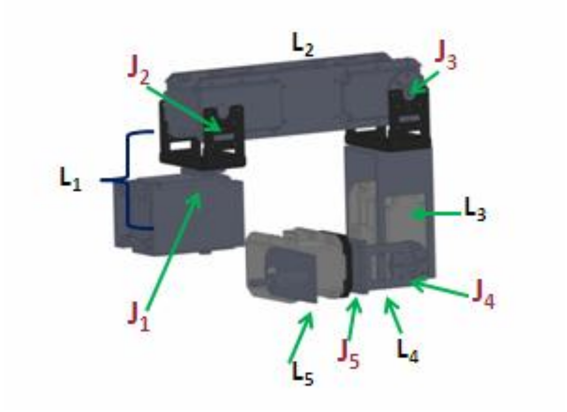


Figure5: Schematic of Mini Manipulator Withjoints and link numbers

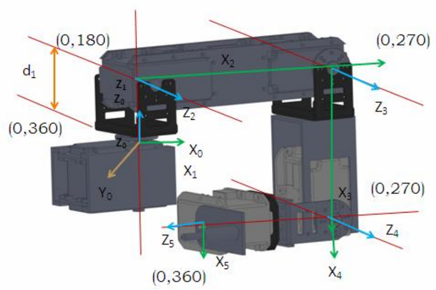


Figure6 Attachment of frames to the various links

Figure 5 and 6 shows Schematic of Manipulator with joints and link numbers and reference frames for finding D-H parameters of the manipulator arm respectively.Denavit-Hartenberg parameters (D-H parameters) for the manipulator are listed below in table 1 where I is the joint number, **α**is linktwist, a is link length, d is link offset and **θ** is joint angle.

Table 1

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	d1	θ_1
2	90	0	0	θ_2
3	0	a_2	0	θ_3
4	0	a_3	0	θ_4
5	90	0	d_5	θ_5

Here the values of link parameters are d_1 =150 mm, a_2= 800 mm, a_3 = 600 mm, d_5 = 300 mm
L = $d_1 + a_2 + a_3 + d_5$ = 1850mm. Joint variables
Variation of different joint angles are as follows
θ_1 varies from 0 to 360 degree.
θ_2 varies from 0 to 180 degree
θ_3 varies from 0 to 270 degree
θ_4 varies from 0 to 270 degree
θ_5 varies from 0 to 360 degree

3.2 Direct Kinematics

$$^0T_5 = {}^0T_1 \times {}^1T_2 \times {}^2T_3 \times {}^3T_4 \times {}^4T_5$$

So, we will get a 4 x 4 matrix, which is a combination of rotation matrix, position vector, prospective and scaling factor for frame 5 with respect to frame 1. The first 3x3 matrix is the rotation matrix and the first three entries of the last column is the position vector in terms of Cartesian Co-ordinates i.e. [xy z]^T.

$$^0T_5 = \begin{bmatrix} r_{11} & r_{12} & r_{13} & P_x \\ r_{21} & r_{22} & r_{23} & P_y \\ r_{31} & r_{32} & r_{33} & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where
$r_{11} = \cos\theta_1[\cos(\theta_2+\theta_3)+\theta_4]\cos\theta_5 + \sin\theta_1\sin\theta_5$
$r_{12} = -\cos\theta_1[\cos(\theta_2+\theta_3)+\theta_4]\sin\theta_5 + \sin\theta_1\cos\theta_5$
$r_{13} = \cos\theta_1\cos\theta_5[\cos(\theta_2+\theta_3+\theta_4)+\sin\theta_1\cos\theta_5$
$r_{14} = \cos\theta_1[300\sin(\theta_2+\theta_3+\theta_4)+\theta_4 + 600\cos(\theta_2+\theta_3) +800\cos\theta_2]$
$r_{21}=\sin\theta_1\cos(\theta_2+\theta_3+\theta_4)\cos\theta_5 - \cos\theta_1\sin\theta_5$
$r_{22}=-\sin\theta_1\cos(\theta_2+\theta_3+\theta_4)\sin\theta_5 - \cos\theta_1\cos\theta_5$
$r_{23}=\sin\theta 1\sin(\theta_2+\theta_3+\theta_4)$
$r_{24}=300\sin\theta_1\sin(\theta_2+\theta_3+\theta_4)+600\sin\theta_1\cos(\theta_2+\theta_3) +800\sin\theta_1\cos\theta_2]$
$r_{31}=\sin\theta_1(\theta_2+\theta_3+\theta_4)\cos\theta_5$
$r_{32}=-\sin\theta_1(\theta_2+\theta_3+\theta_4)\sin\theta_5$
$r_{32}=-\cos(\theta_2+\theta_3+\theta_4)$
$r_{34}=-300\cos(\theta_2+\theta_3+\theta_4)+600\sin(\theta_2+\theta_3)+800\sin\theta_2+d_1]$

From this, we get the position vector of the end effector in Cartesian co-ordinates in terms of the joint variables. These are derived from matlab calculation

px = 300*(cos(t1)*cos(t2)*cos(t3)-cos(t1)*sin(t2)*sin(t3))*sin(t4)-300*(-cos(t1) *cos(t2)*sin(t3) -cos(t1) * sin(t2) *cos(t3)) *cos(t4) + 600 * cos(t1) *cos(t2)* cos(t3) -600* cos(t1) *sin(t2)* sin(t3) + 800 * cos(t1) *cos(t2)

py = 300*(sin(t1)*cos(t2)*cos(t3)-sin(t1)*sin(t2)*sin(t3))*sin(t4)-300*(-sin(t1) * cos(t2)*sin(t3)-sin(t1) *sin(t2)*cos(t3)) *cos(t4) +600 *sin(t1)* cos(t2)*cos(t3)-600 *sin(t1)* sin(t2)*sin(t3) +800 *sin(t1) *cos(t2)

pz = 300*(sin(t2)*cos(t3)+co

s(t2)*sin(t3))*sin(t4)-300*(-sin(t2) *sin(t3) +cos(t2)*cos(t3))*cos(t4)+600*sin(t2)*cos(t3)+600*cos(t2)*sin(t3)+ 800*sin(t2)+d1

3.3Work Space Envelope

The work space i.e. effective area within which the arm can effectively function, is shown in figure7 and8 respectively. The existence and nonexistence of a kinematic solution defines the work space of the manipulator. Work Space is plotted for the manipulator arm using auto CAD is as below :-

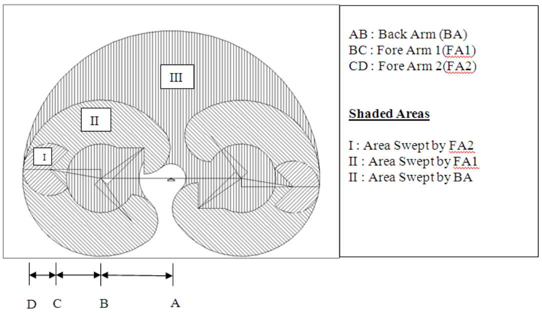


Figure 7Work space in vertical plane

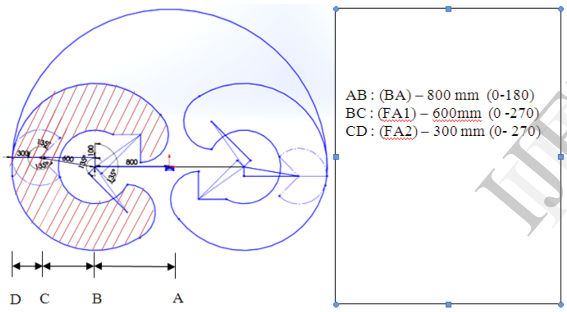


Figure 8 Range of reach for each link

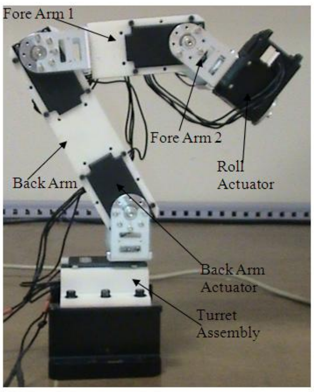


Figure 9 Realization of mini manipulator

4. Conclusion

The manipulator has been designed by considering the different orientation of UXO. The designed manipulator is able to achieve various paths at different angles. Further cross section of the links has been selected to achieve deflection within acceptance limits. FE analysis of the links has been completed. Realisation of mini manipulator has been completed using servo motors. Kinematic analysis has been completed.Realised mini manipulator is shown in figure 9. The manipulator is thus suitable for the task of handling and diffusing of unexploded bombs.

5. Acknowledgement

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6. References

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