Kinematic And Dynamic Analysis Of A Robot Arm Used For All Terrain Robot

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***Abstract*— This paper involves the exploratory development of a all-terrain robot that has excellent mobility performance in the urban environment. The main motivating force behind this project was to have a portable robot to perform urban reconnaissance and surveillance for security purpose, as well as to perform urban search and rescue for civil defense purpose. The scope of the project focused mainly on the design of a robot, which has a maximum speed of 1.5m/s, and is able to overcome 18cm step, 45 degrees slope and climb staircase. The two wheel drive and chain mechanism is made up of the vehicle drive mechanism.**

The ATR has a robot arm attached to it for the purpose of pick and place operation. Arm has two degrees of freedom project involves kinematic and dynamic analysis of the robot arm having two degrees of freedom. The kinematic and dynamic analysis of the arm is carried out using a RoboAnalyzer software. Simulation is done with the help of Simulink toolbox from MatLab software. The results of analysis shows the relationship of velocity, acceleration and torque with respect to time.

***Keywords* — All Terrain Robot, Design, Kinematic Analysis, Dynamic Analysis.**

I. Introduction

Over the past twenty years, as robotics has become a scientific discipline, research and development have concentrated on stationary robotic manipulators, primarily because of their industrial applications. Less effort has been directed to mobile robots. Although legged and treaded locomotion has been studied, the overwhelming majority of the mobile robots which have been built and evaluated utilize wheels for locomotion. Wheeled mobile robots (WMRs) are more energy efficient than legged or treaded robots on hard, smooth surfaces and will potentially be the first mobile robots to find widespread application in industry, because of the hard, smooth plant floors in existing industrial environments. Wheeled transport vehicles, which automatically follow paths & fed by reflective tape, paint, or buried wire, have already found application. WMRs find application in space and undersea exploration, nuclear and explosives handling, warehousing, security, agricultural machinery, military, education, mobility for the disabled and personal robots. Distinguished from common mobile robot in structured environment, all-terrain rovers (ATRs) are a class of mobile robots that have sufficient mobility to enable then traverse over uneven terrain. These robots are being used increasingly in such diverse applications as planetary explorations [1], rescue operations [2], mine detection and demining [3], agriculture [4], military missions [5]. In order to adapt unknown and hazardous terrain, ATRs always have sophisticated mobility systems and the complex mechanisms increase the modeling and analysis difficulty of ATRs.

II. Objectives and Scope

The objectives of this project are to undertake an exploratory development of a all-terrain robot that covers the following points:

a) Mobility:It should be able to run on different terrain without any and climb stair.
b) Tele-operation: It should be able to be remotelyoperated via wireless communication using R.F. Module.
c) Payloads: It should be able to lift a load atleast 2 kg.
d) Analysis:
It involves kinematic analysis and dynamic analysis of the system, finding specifications of different parameters and simulation.

The development of such a robot requires covering of various aspects like mechanical, electronics, testing, software, communication, systems engineering, etc.

III. Literature Survey

In the literature survey, we reviewed the past research and the literature meaning that covered under this project. We studied the basics of the robotic system and the different All Terrain Robots available in the market. We compared these systems according to the type of drive mechanism used, the specification of the robot parameters.

All Terrain Robot means the robot which can travel on different types of ground surfaces. The advances in miniaturisation technologies have given rise new developments in small mobile robotics platforms. Many mobile robots have been developed to reduce human activity in hazardous tasks such as explosive ordnance disposal, nuclear material handling, military operation and urban search and rescue; or in exploratory tasks such as Mars' exploration. Many robots from commercial companies, research institutes,

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universities and government agencies were evaluated, and they were broadly categorized based on their locomotion mechanism into four types of robots namely, legged, wheeled, tracked and re-configurable robots. Several comparison factors were identified based on the objectives of the project. Next, each type of robots was then compared against other type using these comparison factors. A comparison table was then compiled and used to select the most suitable type of locomotion mechanism. In the following sections we will see various types of robots & their comparison.

Factors/Type of robot.	Wheeled.	Tracked.	Legged.	Reconfigurable.
Terrain capabilities.	Limited	Moderate	Good	Good
Stability.	Good	Excellent	Poor	Moderate
Speed.	Excellent	Good	Moderate	Moderate
Payloads.	High	High	Low	Low and Limited
Complexity.	Low	Moderate	High	Very High

The comparison between the four types of mobile robots is summarized in Table. Wheeled robots had been identified as a better locomotion mechanism in terms of overall performance. The tracked robots were not chosen because of their complex design while the legged and re-configurable robots were abandoned due to their small payload size and complexity of mechanism.

Summary of Existing All Terrain Surveillance Robots:

Till now we have studied many wheeled robotic systems, which are used for many operations such as pick and place, surveillance, military applications etc. Every system has some different mechanism used to suit the application. So, we have compared many systems on the basis of the mechanism used, speed, payload capacity, weight, etc.

IV. DETAILS OF THE TOTAL WORK

We wanted to manufacture a All Terrain Robot system which has an manipulator attached to it for the purpose of the pick and place operation. The requirement of the system areas follows:

1.The robot should travel on different terrains for the purpose of surveillance.
2.It should be able to turn in 360 degrees clockwise and anticlockwise at one place.
3. It should be able to climb the stairs.
4.Manipulator arm should be able to extend for certain distance for reaching at an object.
5.Robot arm gripper should grasp the object with proper force.
6.Manipulator should lift the object to a particular height and place it at required position.
7.This ATR should be controlled by wireless communication using R.F. Module.

We had to fabricate the ATR which can fulfil the requirements as stated above.

This ATR system is further developed to achieve more payload capacity and higher accuracy by using a lead screw assembly for a robot arm and pneumatic system for gripper as shown in the figure.

SIMULATION OF A ROBOT ARM

For the purpose of the simulation of the robot arm simulation we used a Simulink toolbox from MATLAB software. The reasons because we used this toolbox are as follows.

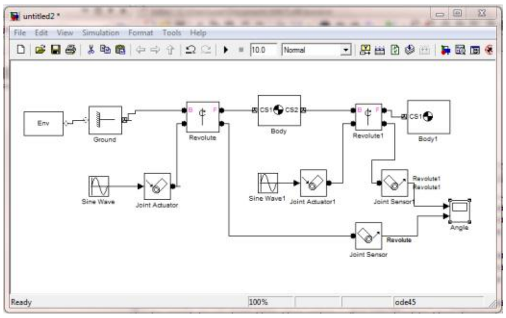
1. It gives information about speed at which arm rotates.

2. It gives graphs showing the angle at which the arm rotates versus time. It is very important because it shows position of the arm at a particular time.

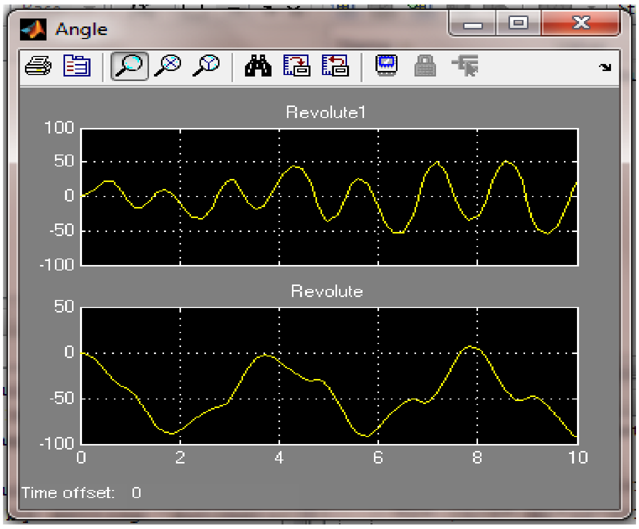
3. This software provides many demos to understand its working regarding to a robot system.

4. It is user friendly.

Using the different blocks of Simulink, we designed a model according to the requirements of the robot arm. It is shown in following figure.



When we run this model by giving command, it shows a graph of angle of joint versus time as follows.



KINEMATIC ANALYSIS OF THE ROBOT ARM

Given the two joint angles, we can calculate the position of the tip of the robot arm using the following equations.

R_f= ($L_1\cos\Theta_1+L_2\cos(\Theta_1+\Theta_2)$)+($L_1\sin\Theta_1+L_2\cos(\Theta_1+\Theta_2)$).

$$X = L_1\cos\Theta_1+L_2\cos(\Theta_1+\Theta_2).$$

$$Y = L_1\sin\Theta_1+L_2\cos(\Theta_1+\Theta_2).$$

We know the values of the links,

$$L_1 = 500 \text{ mm.}$$

$$L_2 = 450 \text{ mm.}$$

Therefore, equations becomes,

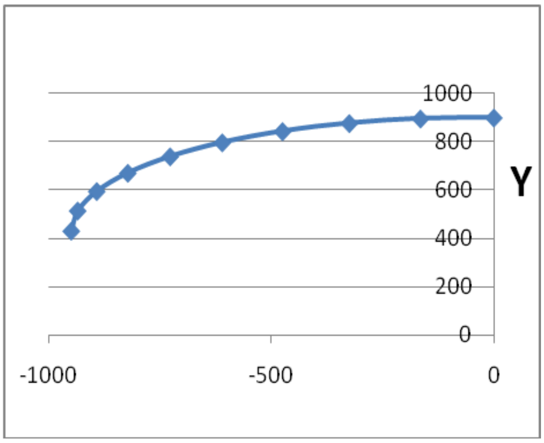
$$X = 500\cos\Theta_1 + 450\cos(\Theta_1+\Theta_2).$$

$$Y = 500\sin\Theta_1 + 450\cos(\Theta_1+\Theta_2).$$

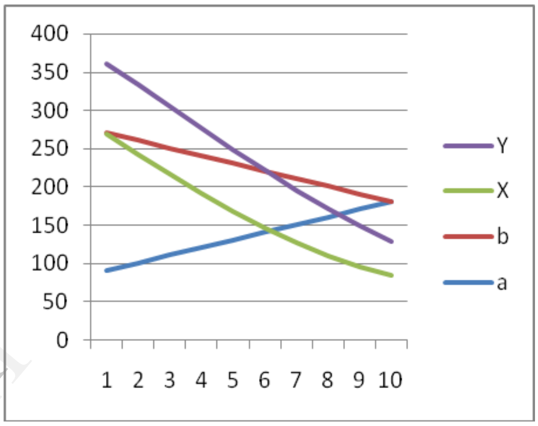
Table: Showing values of X and Y co-ordinates

Θ_1	Θ_2	X	Y
90	180	-0.06769	90.10016
100	160	-16.5549	89.69832
110	140	-32.5397	87.78931
120	120	-47.5367	84.44122
130	100	-61.0908	79.76546
140	80	-72.7906	73.91336
150	60	-82.2809	67.07156
160	40	-89.2737	59.4564
170	20	-93.5567	51.30726
180	0	-94.9999	42.87939

By using the values shown in the table, we plotted graphs of forward kinematic X, Y co-ordinates using Microsoft Excel. These graphs are as follows.



X with respect to Y.



Showing change in all parameters with respect to time.

Abbreviations such as IEEE and SI do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable

. **RoboAnalyzer:**

We used the software, RoboAnalyzer to check the forward kinematics of the robot arm. In this we studied different parameters such as x, y co-ordinate positions, joint values, speed, acceleration etc. RoboAnalyzer is a 3D Model Based Robotics Learning S/W It has been developed to help the faculty to teach and students to learn the concepts of Robotics. It also acts as a supporting material for the contents on various robotics topics in text boo k entitled "Introduction to Robotics", S. K. Saha, 2008. RoboAnalyzer can be used to perform kinematic and dynamic analyses of serial chain robots/manipulators. The foll owing are the main features of RoboAnalyzer:

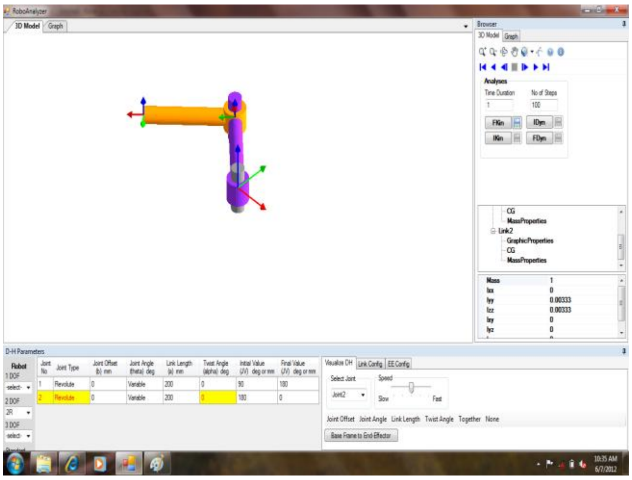
- DH Parameter Visualization.
- Forward Kinematics.
- Inverse Kinematics.
- Inverse Dynamics.
- Forward Dynamics.

To perform the forward kinematic operation, we have to go through the following steps:

1) First we will set the initial and final values of the joint angles. In our case the initial and final values of joint angles are as follows:

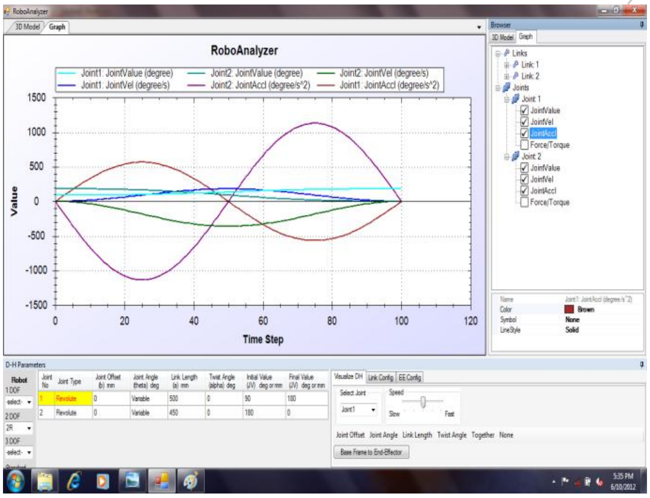
Joint	Initial Value (Degrees)	Final Value (Degrees)
Joint 1	90	180
Joint 2	180	0

2) We will set the time duration as 1s and number of steps equal to 100.
3) Then we will click to FKin button to complete analysis.
4) After analysis is completed, the PLAY button will show us animation and to see the graphs we have to click on GRAPHS and according to selected parameters, the graphs will be shown on screen.

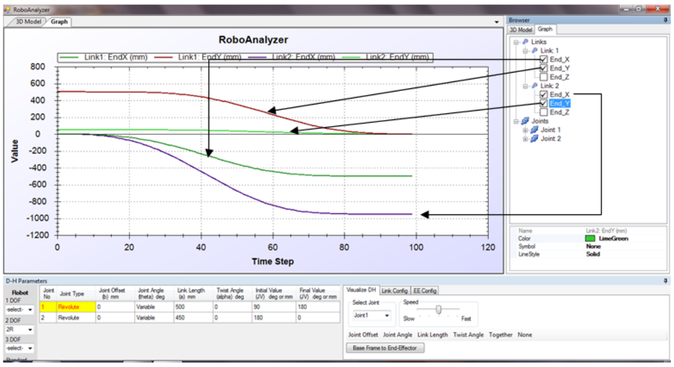


Showing GUI of RoboAnalyzer displaying 2 DOF robot arm.
Results for kinematic analysis are as follows.

A. Unit



Vel., Acceleration, Joint values for both links.



X, Y co-ordinates for both links.

We can analyze its readings and after analyzing these readings we have made following observations.
1. Joint velocity for link 1 is 0 at time frame/step 1. It increases to the maximum value of the180mm/frame at the 51ststep and then again start decreasing and reaches 0 at 100th step.
2. Joint acceleration for link 1, increases with time steps, and reaches its maximum value of 565.4867mm/Frame^2 at 26th step and then starts decreasing.
3. Joint velocity for link 2 is 0 at time frame/step 1. It increases to the maximum value of the360mm/frame at the 51ststep and then again start decreasing and reaches 0 at 100th step.
4. Joint acceleration for link 1, increases with time steps, and reaches its maximum value of 1130.97mm/Frame^2 at 26th step and then starts decreasing.
5. End effecter's x,y co-ordinates at their respected positions are shown in the graph. The fist position is at (0, 50) and last position is at (950, 0).

DYNAMICS

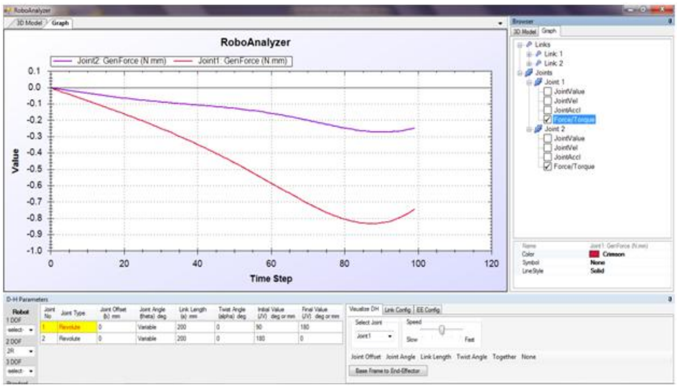
Using the Lagrangian method, derived the equations of the motion for the two degree of freedom robot arm as shown in fig. The center of mass for each link is at the center of the each link. The moment of inertias are I_1 and I_2.
To write the equations of motion, we define the Lagrangian, 'L', as thedifference between the kinetic and potential energy of the system. Thus,

$$L = K – P.$$

Where, 'K' is the kinetic energy of the system and 'P' is the potential energy of the system.
Taking the derivatives of the Lagrangian and substituting the terms into eq^n., yields the following two equations of the motion.

$$T_1= (1/3\ m_1l_1^2+ m_2l_2^2 +1/3\ m_2l_2^2+m_2l_1l_2C_2)..\theta_1+(1/3\ m_2l_2^2+ 1/2\ m_2l_1l_2C_2)..\theta_2-(m_2l_1l_2S_2).\theta_1\ .\theta_2- (1/2\ m_2l_1l_2S_2).\theta_2^2 +1/2(m_1+ m_2)gl_1C_1+ 1/2\ m_2gl_2C_{12}. \quad (1)$$

$$T_2= (1/3\ m_2l_2^2+1/2\ m_2l_1l_2C_2)..\theta_1+(1/3\ m_2l_2^2)..\theta_2+ (1/2\ m_2l_1l_2S_2).\theta_1^2+ 1/2\ m_2gl_2C_{12}. \quad (2)$$



Force and torque for link 1 and link 2.

Figure shows the result obtained for dynamic analysis.

5Parameter Tests:

We carried out different tests to find out some working parameters of the robot. That are as follows.

1) Work volume:

The robot arm has 2 links, first link is 500mm in length and second link is 450mm in length. The arm has only 2 degrees of freedom. So it can move only in XY plane. So it reaches the maximum distance to grip the object horizontally and vertically is 950mm.

2)Payload:

The robot arm can lift the weight of 2kg including the weight of the motors on it.

3)Speed of joints:

Speed of first and second joint is 60rpm.

4) Battery capacity:

The robot can run continuously for one hour, when started with the fully charged battery.

5) Step-up operation:

With fully charged battery, robot can climb around 90mm and as charging of battery reduces, that means when power reduces, the climbing capacity also decreases.

6) R. F. Module Range:

For this ATR, the particular used R. F. Module has a range of around 2.5m.

7) Speed:

The ATR can run with the speed of 1.5 m/s on the surface without load.

The manufactured All Terrain Robot is able to climb a stair and has a attached robot arm which has two degrees of freedom. Simulation and kinematic analysis of the robot arm has been carried out andthe different performance parameters of the ATR have been checked.

CONCLUSION

1. The A.T.R. system completed is able to run on different terrains such as smooth and hardsurfaces with the speed of 1.5 m/s. and able to climb a stair of height of 100mm.
2. Kinematic analysis has given a result which shows that velocity for joint 1 and joint 2 increase up to a certain point and then drop down to zero. It also shows the behavior of acceleration at different points of time step. For this purpose we used aRoboAnalyzer software.
3. Dynamic analysis has given a result which shows that the torque value changes with respect to the rate of change of robot configuration(ϴ). Dynamic analysis is done with the help of the RoboAnalyzer software.
4. Simulation of a robot arm is completed with the help of Simulink toolbox from MatLab software which clearly indicates how robot configuration changes with respect to time in the form of the graphs.

This ATR can be used for many applications such as,

i) Surveillance.
ii) Military operations.
iii) Resque operations.
iv) Material handling operations.

Future scope:

Due to limitation of time, there are still many aspects of the project, which can be improved further. They are as follows.

1) Scanner: There is possibility to attach a scanner to ate robot arm so that it can able to scan the objects and can be used as Bomb Detection And Disposal Squad.

2) Wireless Camera: We can use a wireless camera for object recognition and obstacle avoidance.

3)Stair climbing capacity: Now this is able to climb a step height of 100mm. It can be developed further using high torque motors.

4) Payload capacity: Robot arm is able to lift a load of 2kg including the weight of motor assembly. It should able to lift atleast 5 kg. So change should be made in the mechanism of the robot arm to get appropriate result.

5) Night vision: We can attach aA night vision device ('*NVD*') to the ATR, which is an optical instrument that allows images to be produced in levels of light approaching total darkness. They are most often used by the military and law enforcement agencies, but are available to civilian users. The term usually refers to a complete unit, including animage intensifier tube, a protective and generally water-resistant housing, and some type of mounting system.

6) Water disruptor:We can use a device called as water disruptor which is used to destroy bombs using a water projectile shaped charge.

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