Crane Forwarder-Control Algorithm for Automatic Extension of Prismatic Link

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Abstract

The main objective of this paper is to develop and control the length of the extension boom for the automated heavy vehicles, especially in the areas of control systems and robotics. It provides a display screen where the parameter values of swivel arm angle lift arm angle, elbow arm angle and length of the extension boom can be configurable. To deduce which parameters we need to consider that are needed to be modified. Forwarder kinematics are taken into consideration for the building of the algorithm for the automatic prismatic link which is obtained from the Mat lab code. Then final results are tested on DSP system Crane Box.

Keywords: DSP, Crane Box, Mat lab, D-H Table and Forward Kinematics.

1. Introduction

In the modern area of technological enhancement specifically to the grounds of forestry vehicles, forwarders advancements have the key significance. Various researches are mainly concentrated on improved control algorithms for the cranes, which make use of automation as the means of driving force. [2-3] This helps to reduce the time consumption and speeds up the operation and makes itself operator friendly.

The operator controls the crane through the joysticks. The operator's joysticks directly control the oil flow to the hydraulic valves in the crane to which the powerful hydraulic system is attached. Each joystick controls its respective link in desired direction. The operation is very fast and can be actuated by the hydraulic cylinders. An automatic system is present that controls the extension boom of the crane. In standard case the operator controls majorly the turntable, first boom and outer boom of the crane. The operator in order to adjust the behavior of extension link is automatic. Some other parameters can be configured to get the crane working. Thus the operator is provided with a screen where in which, controls the crane with his choice of parameters modification. The TFT monitor is used in order to fulfill this job in our research work for the parameter configurations.

In our present research describes the design of automated heavy vehicles, especially in the areas of control systems and robotics. The field of automation has gained its importance making operation of heavy vehicles much easier e.g., in the design of forwarders. Forwarders are used to cut down trees and to collect logs from the ground. Forestry based industry make use of these forwarders usually. Cranes along with the forwarders are also widely used in the forestry applications.

In general, cranes need to execute several movements such as used to lift heavy loads and also moving loads from one place to the another place. The design of forwarders can be in various sizes, according to the loads they carry. The main objective for this work is to improve the working condition for the forwarder operator, by means of partly automate the crane. This paper is about implementation of an algorithm for automation of one crane link i.e., specifically the prismatic link.

2. Kinematics of the Crane:

Crane geometry

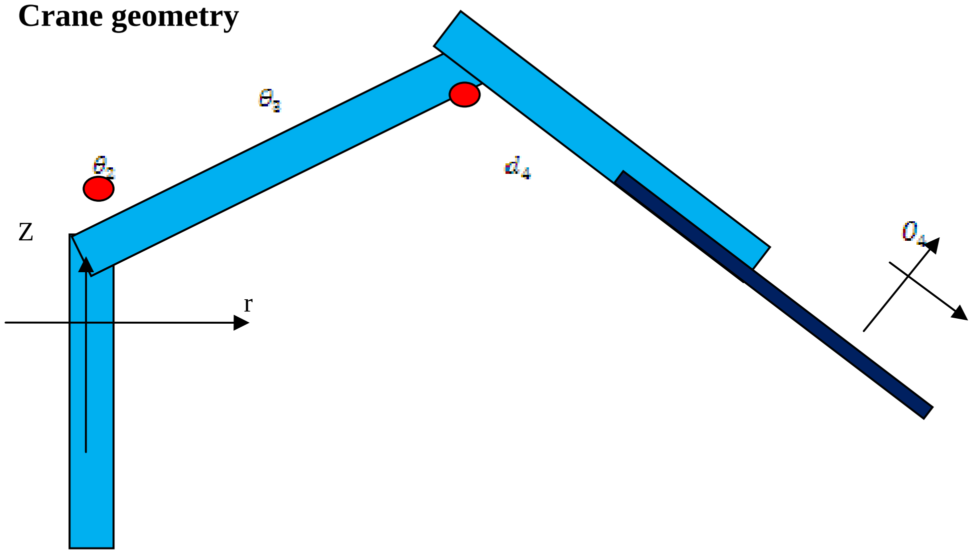

Figure 1: Forward crane geometry in two dimensions

In Figure 1 the forwarder crane is represented in two dimensions. The swivel joint θ_1 is left out in our case in order to be able continue our presentation into the two dimensional case. [4-5]The crane tip position, O_4, can be represented in Cartesian coordinates, r and z or in terms of crane coordinates θ_2, θ_3 and $d_4$from the Figure 1. From the crane geometry we have θ_1, $\theta_2$and θ_3 are the angles of rotation at the links. The value θ_2, θ_3 reprensent various links such as swivel arm , lift arm and elbow arm respectively. Thus the value of angles of rotation can be the parameters of choice.

Where, θ_1 is the swivel arm angle in radians,

θ_2 is the lift arm angle in radians,

θ_3 is the elbow arm angle in radians,

d_4 is the length of the extension boom in length (meters),

And, O_4 is the crane tip position.

Crane Coordinates:

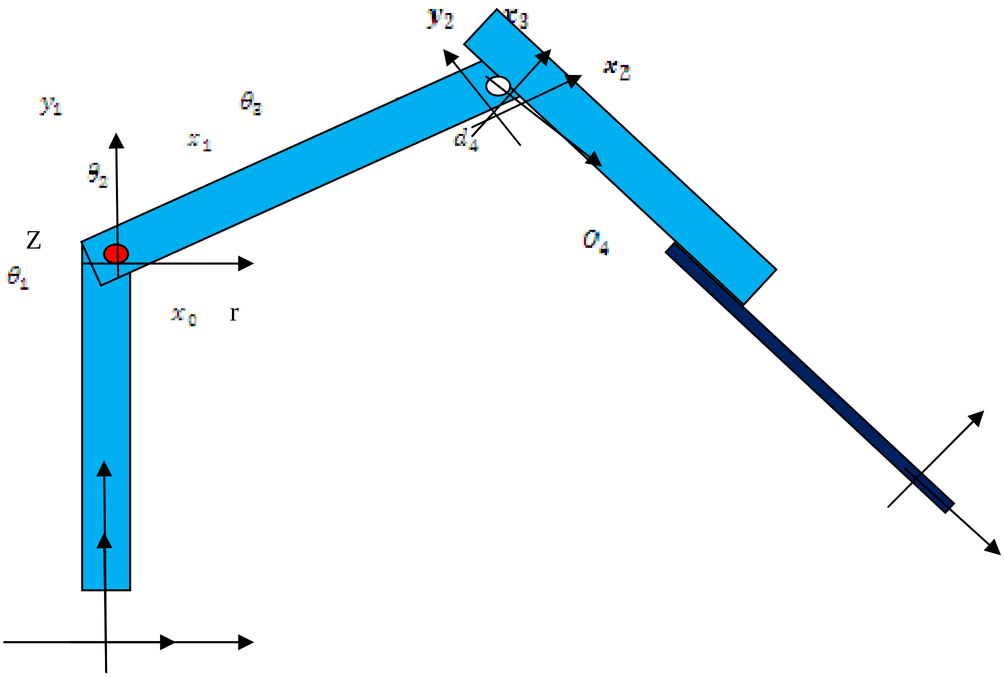

Figure 2: Crane coordinate according to Denavite-Hartenberg Table

Forward Kinematics

The forwarder kinematics can be derived using methods presented in [9]. According to Denavite-Hartenberg the transformation matrix transforming the coordinates between two subsequent coordinate system, from system i to system i-1, is given by the following relation as,

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

From the conventions of the forward kinematics of the crane and the Denavite-Hartenberg the transformations, we have designed the relations of the various parameters which are represented in the following. The four parameters behind the Denavite-Hartenberg Table are that θ,d, a and $\propto$ which are obtained from the crane. But in our implementation Jacobian is taken into consideration instead of forward kinematics in the development of the automatic extension boom algorithm.

The corresponding ***D-H table*** is given in Table 1. **[1]**

DH-table, Crane	θ	d	a	$\propto$
Swivel arm, link1	$\theta_1 = 0$	$d_1 = d_1^*$	$a_1 = 0$	$\propto_1 = \frac{\pi}{2}$
Lift arm, link2	$\theta_2 = 0$	$d_2 = 0$	$a_2 = a_2^*$	$\propto_2 = 0$
Elbow arm, link3	$\theta_3 = 0$	$d_3 = 0$	$a_3 = 0$	$\propto_3 = \frac{\pi}{2}$
Prismatic arm, link4	$\theta_4 = 0$	$d_4 = d_4^*$	$a_4 = 0$	$\propto_4 = 0$

Table 1: Denavite-Hartenberg table for the crane considered.

The transformation matrices for the crane model are given by the following relation as,

$$T_0 = \begin{bmatrix} 1 & 0 & 0 & a \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_1 = \begin{bmatrix} cos\theta & -sin\theta & 0 & 0 \\ sin\theta & cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(alpha) & \cos(alpha) & 0 \\ 0 & \sin(alpha) & \cos(alpha) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

and

$$T_4 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The transformation from the crane tip position to the O_0 is given by the relation as,

$$T_4^0 = T_0 T_1 T_2 T_3 \quad (2)$$

The O_4 i.e. the origin in the fourth coordinate system is the position expressed in (O_0, x_0, y_0, z_0) is given by the relation as,

$$p_0 = T_0 T_1 T_2 T_3 O_4$$

The forwarder kinematics for the crane when $\theta_1 = 0$ is given by the relation as,

$$p_0 = \begin{pmatrix} x_0 \\ z_0 \end{pmatrix} = \begin{pmatrix} a_2 cos\theta_2 + d_4 \sin(\theta_2 + \theta_3) \\ d_1 + a_2 sin\theta_2 - d_4 \cos(\theta_2 + \theta_3) \end{pmatrix} \quad (3)$$

This forwarder kinematics are calculated manually and taken into consideration for the building of the algorithm for the automatic prismatic link. This includes some linear algebra that can be understood by the translation and the rotations of the axes.

The Jacobian Matrix:

The Jacobian for the crane operating in two dimensional space extended by (x_0, z_0), can be obtained by taking the derivation of the corresponding forwarder kinematics of the crane. The Equation (3) is made to take the derivative of the forwarder kinematics typically.

Cartesian velocity equals the Jacobian times joint velocity in the observations done. The derivation is performed when swivel joint is considered to $\theta_1 = 0$ and the coordinates x_0 coincides with the coordinate **r**. The Cartesian velocity relation can be explained in the following relation as,

$$v = J(q)\dot{q} \quad (4)$$

Jacobian is a function of q it is not a constant.

$$J(q) = \frac{\partial h(q)}{\partial q} = \begin{pmatrix} \frac{\partial h_1}{\partial \theta_2} & \frac{\partial h_1}{\partial \theta_3} & \frac{\partial h_1}{\partial d_4} \\ \frac{\partial h_2}{\partial \theta_2} & \frac{\partial h_2}{\partial \theta_3} & \frac{\partial h_2}{\partial d_4} \end{pmatrix}$$

Where $q = \begin{bmatrix} \theta_2 \\ \theta_3 \\ d_4 \end{bmatrix}$ implementing the Jocobian Matrix.

Equation (3) is derivated in order to obtain the Jacobian.

The Jacobian Matrix is given by the relation as,

$$J(q)=\begin{pmatrix} -a_2 sin\theta_2 + d_4 \cos(\theta_2+\theta_3) & d_4 \cos(\theta_2+\theta_3) & \sin(\theta_2+\theta_3) \\ a_2 cos\theta_2 + d_4 \sin(\theta_2+\theta_3) & d_4 \sin(\theta_2+\theta_3) & -\cos(\theta_2+\theta_3) \end{pmatrix} \quad (5)$$

We now proceed in discussing to the other functions that are involved in building the algorithm of the crane.

Angular Velocities ($\dot{\theta}_2, \dot{\theta}_3, \dot{d}_4$) of the crane links

The Cartesian velocities in two dimensions case is given by the relation as follows,

$$v = \begin{pmatrix} v_x \\ v_z \end{pmatrix} = \frac{d}{dt}\begin{pmatrix} r \\ z \end{pmatrix} = \frac{d}{dt}\begin{pmatrix} x_0 \\ z_0 \end{pmatrix} \quad (6)$$

This can be calculated as follows,
$v = J(q)\dot{q}$

Where $\dot{q} = \begin{bmatrix} \dot{\theta}_2 \\ \dot{\theta}_3 \\ \dot{d}_4 \end{bmatrix}$ (7)

The values of the angular velocities can be obtained from the sensors in the practical environment. In the development of the algorithm the maximum joint velocities are also considered $\dot{\theta}_{2m}, \dot{\theta}_{3m}, \dot{d}_{2m}$.

3. Implemented crane parameters

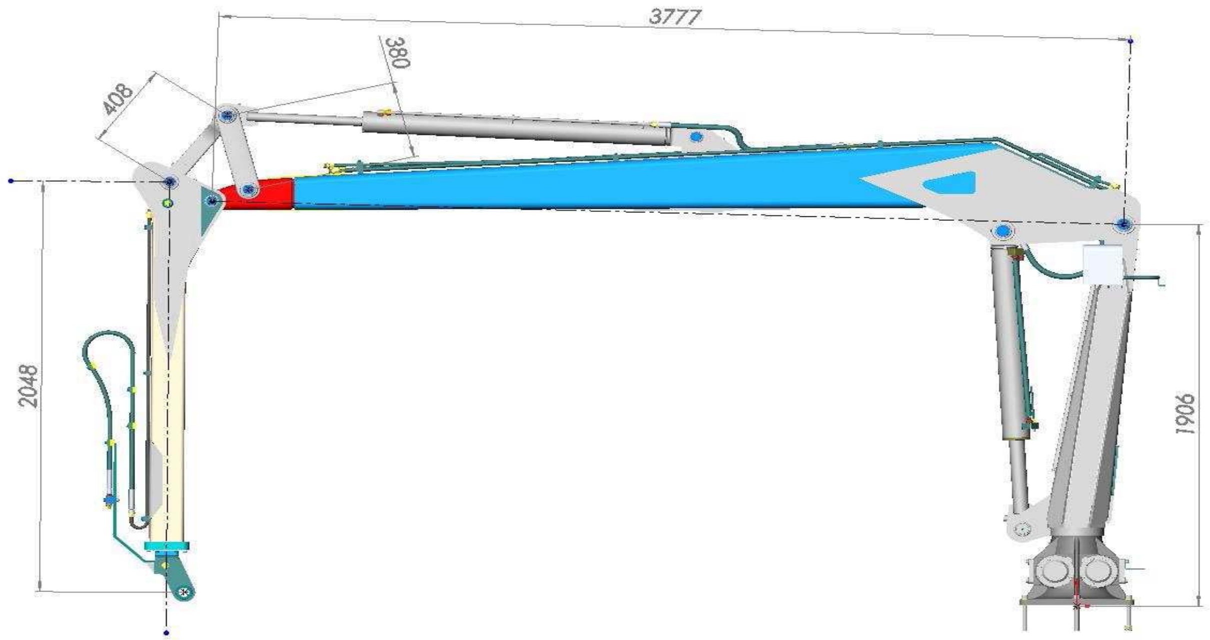

Figure 3: Crane parameters

Figure 3 shows the parameters such as the elbow arm, lift arm and the extension link in order to operate the crane. With these values we need to operate the crane in the practical cases in the crane lab environment. We deduced the parameters those to be implemented in the control algorithm. [6-8]The implementation of the algorithm should be compatible with the Real Crane. This is also one of the aspects taken in account to reach the goal, which is testing of the algorithm in the practical environment.

4. Results and Discussions

We have implemented Crane Forwarder-Control Algorithm for Automatic Extension of Prismatic Link in mat lab and observed all the results successfully. Figure 4 shows the crane files run an animation in 3 dimensional and present the results in x0 and z0 coordinates. We have plotted the crane inverse jocobian function. Figure 5 shows the Crane, kinematic trajectory, go to a log on the ground. These are observed when the Crane moving upwards case, plotted the lateral position x and height z. Figure 6 shows the Crane, Kinematic trajectory, movement of only elbow arm. These are observed when the crane moving downwards case, plotted the lateral position x and height z. These two results are use full for avoiding of crane damage, in case of occurs these problems automatically crane goes to zero position.

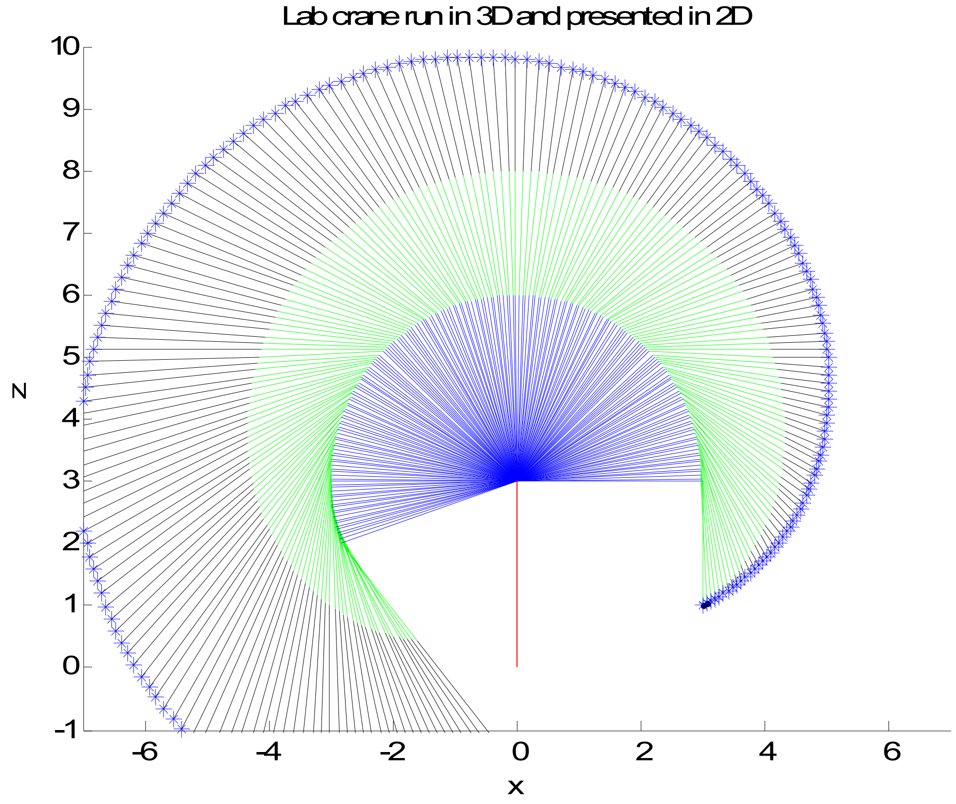

Figure 4: Crane Inverse Jocobian implementation

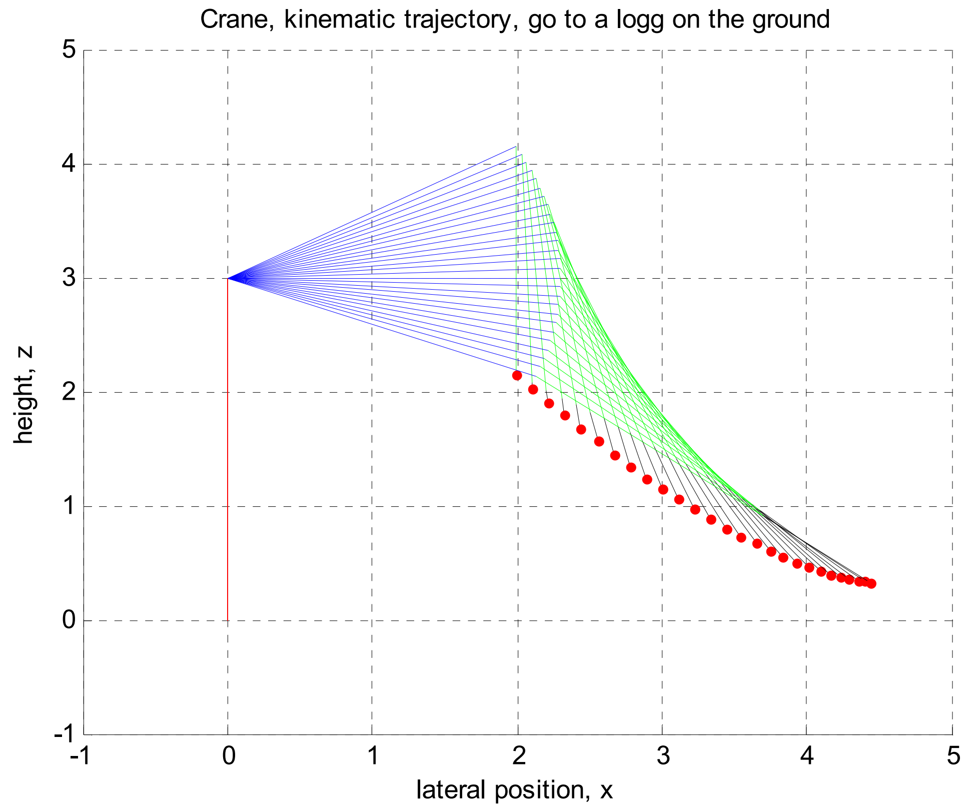

Figure 5: Crane ,kinematic trajectory, go to a log on the ground

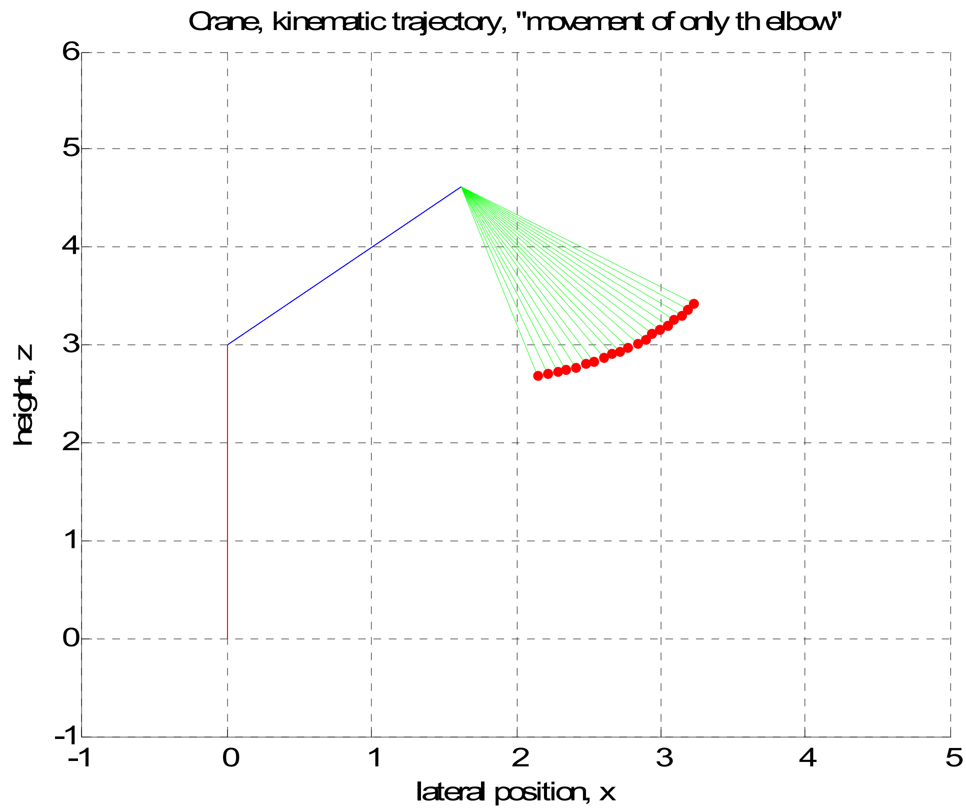

Figure 6: Crane,Kinematic trajectory, movement of only elbow arm

5. Conclusion

In this paper we have improved the working condition for the forwarder operator. We have implemented forward kinematics and angular velocities in the Automatic prismatic algorithm. The code was implemented in Mat lab. We have reduced the number of operations operated by the operator and observed the automatic extension of the extension boom.

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