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# Design and Control of Snake-Like Robot for Smooth Terrain

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**Abstract:- The improvement of rescue robots has been vigorously in perilous surroundings for investigate and rescue processes. The secure genus of mobile robots is called snake-like robot. In this work, the frame design of snake-like robot model has been accomplished based on the control function with mathematical geometry. The tracking path for snake-like robot was established with the circular path. And then the estimation between the actual tracking and original path could be analysed with the help of MATLAB programming. In this paper, the robot head position is controlled to converge the desired trajectory tracking. The tracking error could be reduced by using proportional controller. The enactments of the tracking paths for snake-like robot was expressed with the simulation results.**

***Keywords:-*** *Trajectory Tracking; Snake-Like Robot; Proportional Controller; MATLAB.*

## I. INTRODUCTION

Snake robots involve an essential part in explore and rescue processes such as firefighting, investigation and safeguarding in recently years. Snake robot easily passes through rough terrain such as destroyed construction or confusion situation caused by a vehicle accident in a subway. The snake-like robot could creep through devastated region to save human life. Snake robot immediately transport required equipment toward any person trapped in the crushed damage construction. A snake robot proposed by Miller in a salvage operation. Besides, the snake robot can use for extreme terrain, survivors search from dangerous areas of manufacturing plants such as nuclear facilities. Snake robot could be checked the drainage system for searching drip or gave support to fireman in an urban. Moreover, robot manipulator can use as a snake robot by connecting with one end fixed at a bottom [1].

Snake-like robots are multi-section mechanism that originates impulsion from groove. The snake-like robot is organically stimulated from genuine snakes to be real and locomotive in branches out environments. According to the features of topography talent, scalability, great permanence, and earth flexibility, this robot can also be used in various function such as pipeline mending, reconnaissance, medical purpose, space investigation etc. Snake-like robot are created by attaching together a number of liberate links. Snake-like robots can travel into constricted spaces because the shape of the body is small and slightly. The rescue robot are anticipated to be active for explorations in constricted spaces and over debris in earthquake shattered areas because of the elongated and slim shape [2] and [3].

In this paper, trajectory tracking for smooth terrain was developed. Snake- like robots is difficult to control because it has several internal joints. The kinematic model is obtained by using geometrical relation and velocity constraints. A kinematics model takes the details of robot's geometry. In the presented work, the snake-like robot model is designed by connecting serially four links with two degree-of-freedom active joints. The trajectory tracking of four links snake- like robot is controlled by using proportional control system.

The paper contains six section. Section II presents robot model. Section III demonstrates control system of snake-like robot. Section IV presents the trajectory Tracking with Proportional Controller. Section V discusses on the implementation of snake-like robot. And Section VI mentions the simulation results of the analysis. . Section VII includes conclusion of proposed work.

## II. SNAKE-LIKE ROBOT MODEL

The various snake robot designs are recognized to categorize certain basic properties such as type of joints, features of motion and with or without inactive caster wheels. Furthermost, the majority of snake-like robots are consisting of links joined by rotating joints with one or two degrees of freedom. The mathematical modelling of the different snake-like robots is divided into kinematics and dynamics. In this work, snake-like robot model is designed with four links and three joints. The kinematics model is based on geometrical relation but without consider force. Fig. 1 shows four links snake robot model.

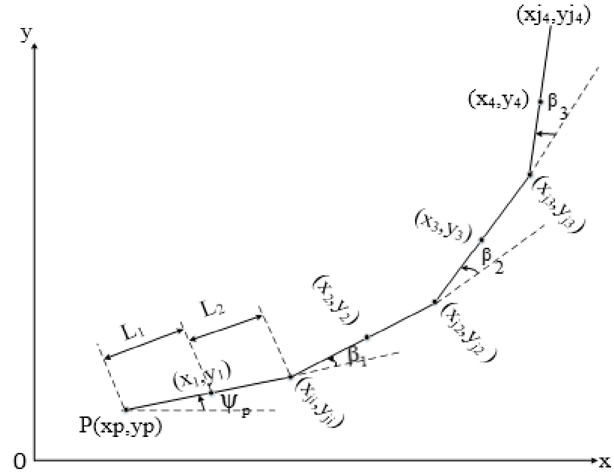

Fig 1:- Four Links Snake-Like Robot Model

Snake-like robot is move forward by twisting left and right of the links. So, this robot is difficult to control the defined path. Consequently, the orientation angle can be described as $\psi_i = \psi_p + \sum_{k=1}^{i-1}\varphi_k$ . The center of unit i of first link is described in the Equation 1 and Equation 2.

$$x_i = x_p + L_1\cos\psi_p + \sum_{j-1}^{i-1}\left(L_2\cos\psi_j + L_1\cos\psi_{j+1}\right) \quad (1)$$

$$y_i = y_p + L_1\sin\psi_p + \sum_{j-1}^{i-1}\left(L_2\sin\psi_j + L_1\sin\psi_{j+1}\right) \quad (2)$$

Where $\psi_1 = \psi_p$ the velocity condition is require in the description. So, the velocity equation for the center of first link can be expressed in Equation 3 and Equation 4.

$$\dot{x}_i = \dot{x}_p + L_1\dot{\psi}_p\sin\psi_p - \sum_{j-1}^{i-1}\left(L_2\dot{\psi}_j\sin\psi_j + L_1\dot{\psi}_{j+1}\cos\psi_{j+1}\right) \quad (3)$$

$$\dot{y}_i = \dot{y}_p + L_1\dot{\psi}_p\cos\psi_p - \sum_{j-1}^{i-1}\left(L_2\dot{\psi}_j\cos\psi_j + L_1\dot{\psi}_{j+1}\cos\psi_{j+1}\right) \quad (4)$$

Velocity constraints condition is considered to get kinematic model. The velocity constraints equation can be described in Equation (5).

$$\dot{x}_i\cos(\alpha_i + \psi_i) + \dot{y}_i\sin(\alpha_i + \psi_i) + r\dot{\theta}_i\sin\alpha_i = 0 \quad (5)$$

According to the above equation, the kinematic model equation can be expressed in Equation 6.

$$A\dot{\omega} = Bu \quad (6)$$

In this model, $\omega = \left[x_p\ y_p\ \psi_p\ \beta_1\ \beta_2\ \beta_3\right]^T$ is the position vector to be controlled and $u = \left[\dot{\theta}_1\,\dot{\theta}_2\,\dot{\theta}_3\,\dot{\theta}_4\,\dot{\beta}_1\,\dot{\beta}_2\,\dot{\beta}_3\right]^T$ is control input vector. Table 1 is the system parameter.

| | |
|---|---|
| ω | Robot's position vector |
| u | Robot's control input vector |
| $\beta_i$ | Joint angle |
| $(x_p, y_p)$ | Robot heat position |
| ω | Orientation angle of first link |
| ξ | Trajectory of control parameter |
| $\alpha$ | The angle of the $i^{th}$ unit |
| $l_1, l_2$ | Length between the joint and center of unit |
| $(x_i, y_i)$ | The position of $i^{th}$ segment center of unit link |
| $\alpha$ | The angle of the $i^{th}$ unit |
| $(x_{ji}, y_{ji})$ | The position of $i^{th}$ segment center of link |

Table 1:- System Parameter of Model

## III. CONTROL SYSTEM

Fig. 2 shows the control system of robot model. In the control system, Firstly, four link snake robot model is designed by connecting four links robot arms and three active joints serially. And then, kinematic equation is calculated by using geometrical relation. A control equation for trajectory tracking is designed in this work. The closed loop control system is obtained by substitution control equation for trajectory tracking in kinematic model. The system is designed with feedback control system by using proportional gain.

Euler's method is used to solve first order differential equation. If the control system does not meet desired tracking, the system is optimized again by using feedback control system. If the system converges desired tracking, the control system is finished. In this paper, the aim of the system is to reach specific location by controlling with the feedback control system .

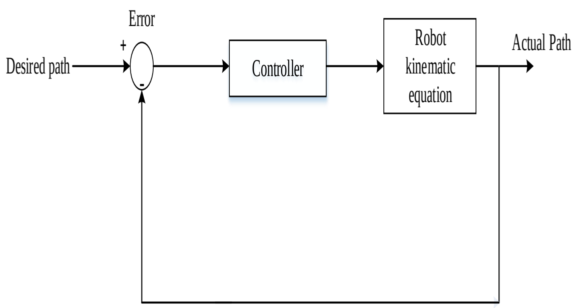

Fig 2:- Control System of Robot Model

## IV. TRAJECTORY TRACKING WITH PROPORTIONAL CONTROLLER

The best part of the controlling loops in the manufacturing process use the proportional control. PID controllers are commonly used numerous types of processes because of the most general research has motivated on the closed-loop stability, enactment and healthiness. The different types of controllers are used to control target path in a robot arm design. In this paper, proportional gain is used to stable for the path tracking. In the proportional control procedure, the output of a proportional controller is the multiplication of the error signal and the proportional gain. The proportional control method is developed for straight line tracking in this paper. The proportional gain is reduced the error by controlling the serial links of snake robot. First step input is applied to the kinematic equation to study the features of the system. And then, the complete output response of the system appears by manual tuning proportional gain.

The control law of path tracking is designed as the Equation 7. Equation 8 shows the error of the system. The error is the different between the desired path and the definite path of the system. The closed-loop equation is describe in Equation 9.

$$u = B^{-1}A\left(\dot{\xi}_d - Ke\right) \tag{7}$$

$$e = \xi - \dot{\xi} \tag{8}$$

$$A\left(\dot{\xi} + K_d\right) = 0 \tag{9}$$

Where $\xi_d$ is a given target trajectory, $\xi$ is actual tracking and K is a given proportional gain matrix. Table 2 is the simulation parameters of model.

| Parameters | Value |
|---|---|
| Kp | 0.5 |
| $L_1, L_2$ | 0.5 meter |
| $\alpha_i$ | $\pm\frac{\pi}{4}$ |
| $R_p$ | 0.7 meter |

Table 2:- The simulation parameters of model

## V. IMPLEMENTATION

The implementation flow chart for snake robot model is shown in fig. 3. This system flow chart initializes symbolic parameters and system parameters. And then, input matrix of trajectory tracking is assigned. After, the system is designed closed loop equation is applied. According to the closed loop equation, continuous equation is appeared. Euler Method is used to transform continuous equation to discrete equation. Matlab symbolic toolbox is used to solve discrete equation. And then, the position, orientation angles and joint angles are obtained by using for loop. Finally, the value of the position, orientation and joint angles are described by using the graph.

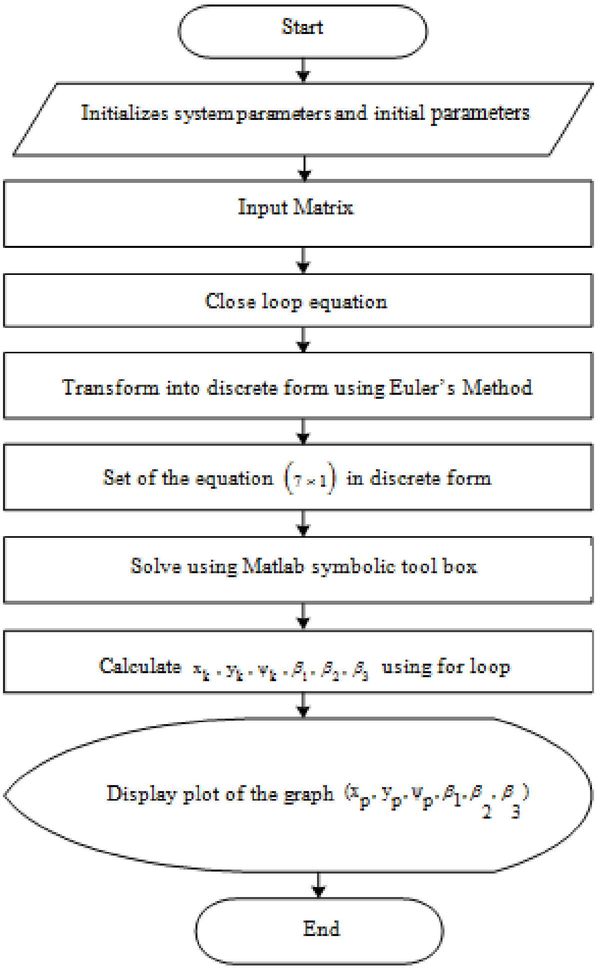


Fig 3:- Implementation Flow Chart of Snake Robot Model

## VI. SIMULATION RESULTS

Based on the system flow chart for snake robot model, the simulation result for trajectory tracking of x-y plot of head position could be analyzed. The simulation result is based on the comparison of control system. The response of head position p is compared by using feedback and feedforward control system for fixed joint angle. The initial trajectory tracking condition is zero and desire trajectory tracking condition is $\left[R_p\cos\frac{\pi}{16}t, R_p\cos\frac{\pi}{16}t, \frac{\pi}{16}t-\frac{\pi}{16}t-\frac{\pi}{2}-\frac{\pi}{2}, 0,0,0\right]$ in the feed forward control.

Fig. 4 shows comparison of path tracking for robot model. According to this simulation result, the solid line is feedforward control system and dotted line is feedback control system. The path tracking of robot model is based on the circular path. In this result, the value of proportional controller is zero in feedforward control system. In the following results, feedforward control system is obviously far away from the specified circular path. Therefore, feedforward control system is cause huge tracking error.

So, feedback control system is used to reach specified circular path by adjusting proportional gain. the value of proportional controller is 0.5 in feedback control system. The initial trajectory condition is zero and desire trajectory condition $\left[R_p\cos\frac{\pi}{16}t, R_p\cos\frac{\pi}{16}t, \frac{\pi}{16}t-\frac{\pi}{16}t-\frac{\pi}{2}-\frac{\pi}{2}, -0.283, -0.283, -0.283\right]$ is in the feedback control system. In this result, the path tracking of snake-like robot converges toward the specified circular path.

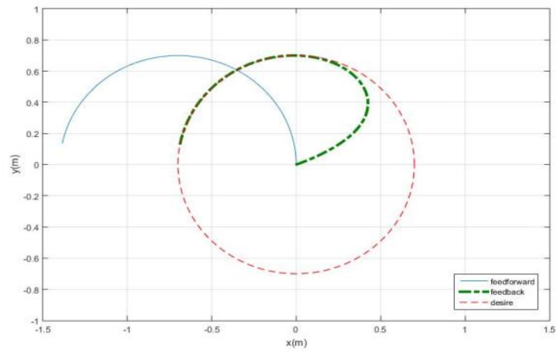


Fig 4:- Comparison for Path Tracking of Robot Model

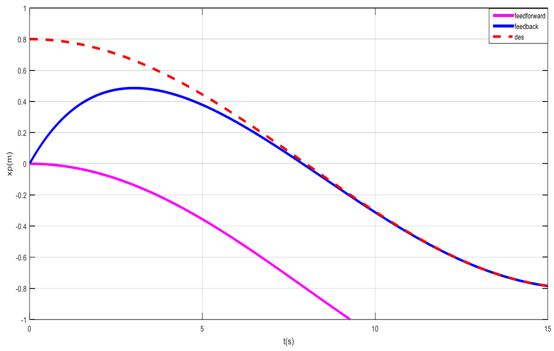


Fig 5:- Comparison for Path Tracking of x-Coordinate

In the Fig. 5 shows comparison for path tracking of x-coordinate. According to this simulation result, the solid line is feedforward and feedback control system. Dotted line is the target tracking. In this result, the feedforward control is slower than feedback control to reach the desire trajectory. Fig. 6 shows comparison for path tracking of y-coordinate. In this result, the feedforward control and feedback control are reached the target trajectory at the same time. Fig. 7 shows comparison for path tracking of orientation angle $\psi_p$. According to the simulation result, feedforward control cannot reach toward target path tracking and feedback control is move toward the target trajectory.

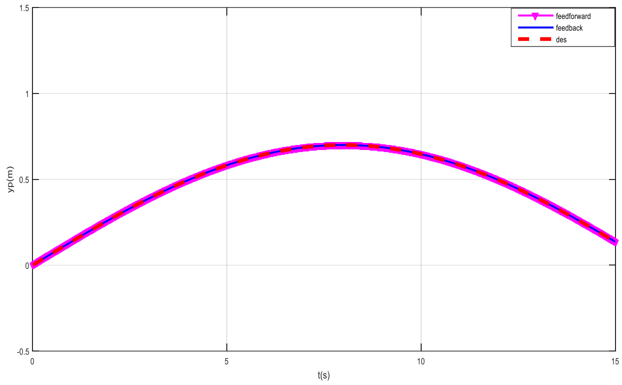


Fig 6:- Comparison for Path Tracking of y-Coordinate

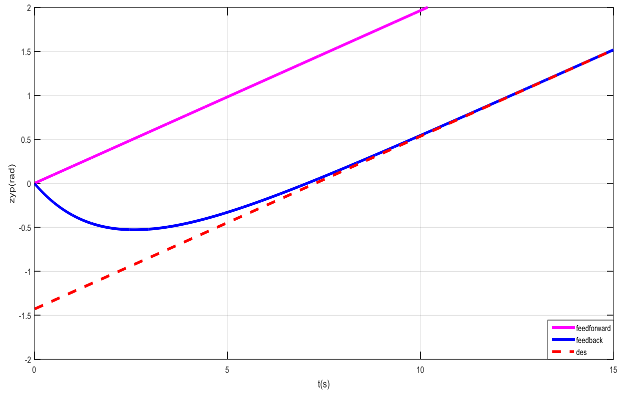


Fig 7:- Comparison for Path Tracking of Orientation Angle $\psi_p$

Fig. 8 to fig. 10 shows comparison for the path tracking of joints. In this result, solid line is actual path tracking and dash line is the target path tracking.

According to the simulation results, path tracking of joint angles meet toward the target localization after 7s. From these result, the state variables are converging toward the target path tracking and the robot will be moves toward the target path. In this control system, the last three links are automatically moved toward the target trajectory by controlling first link.

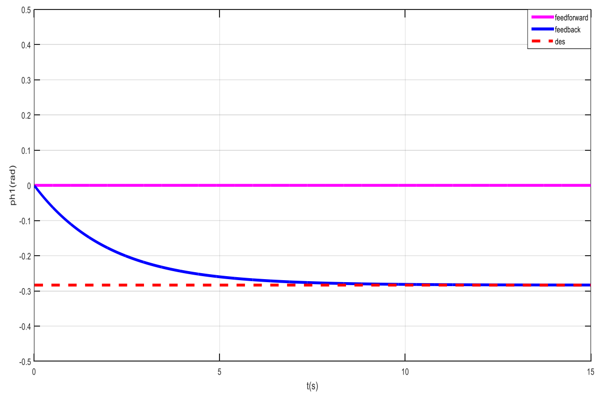


Fig 8:- Comparison for Path Tracking of Joint $\beta_1$

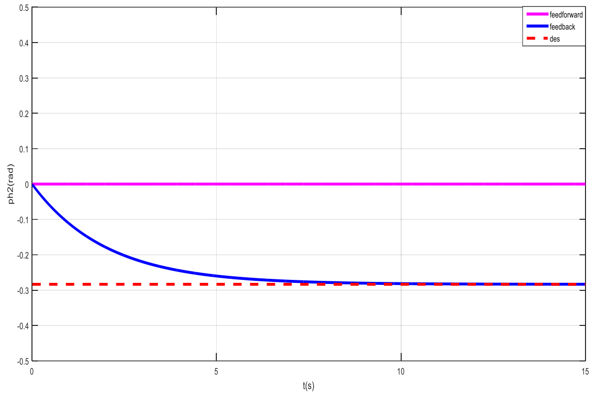


Fig 9:- Comparison for Path Tracking of Joint $\beta_2$

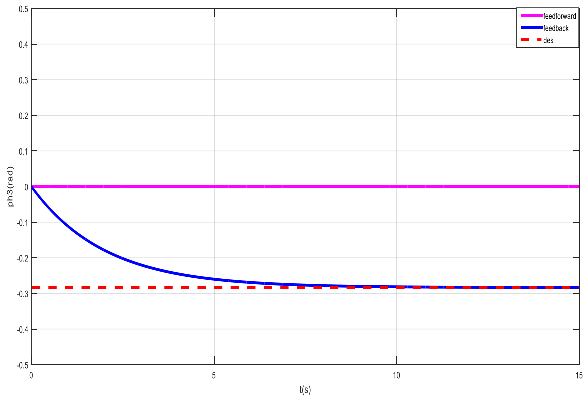


Fig 10:- Comparison for Path Tracking of Joint $\beta_3$

## VII. CONCLUSION

In this paper, the snake robot model is typically created with four segments links that are attached consecutively active joints. The control system of model is developed by using kinematic analysis. By using obtained kinematic model equation, the model of system is simulated in Matlab. The close loop control system is nonlinear first order differential equation. The Euler method is used to solve derivatives of a function. In this paper, Matlab symbolic toolbox is used to display the value of the position, orientation and joint angles as the graphs. Modeling, control and numerical simulation is carrying out using the Matlab software. In addition, the simulation results of four links snake robot model is considered smooth terrain and straight path.

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