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PERFORMANCE IMPROVEMENT THROUGH SCALABLE DESIGN OF MUTLI-LINK 2-DOF AUTOMATED PEDESTRIAN CROWD CONTROL BARRIERS

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ABSTRACT

This paper describes the performance improvement through scalable design of a two degree of freedom (DOF) automated pedestrian crowd control barrier based on a closed-loop feedback control system. Since most of the barriers existing amd used is immobile, static and not adaptable to changing crowd condition. In the proposed experiment, a scalable design of an adaptive system that can assume strictly the role of the security man by sensing the crowd and move away to provide a safe area between crowd people and events area without collision. Kinematic and dynamic analysis to build the system is proposed, while planning trajectory is provided by suggesting some cases to control a specific current crowd situation using Computed Torque Controller (CTC), which identifies the difference between the input desired trajectory with the newly collected data of the equation of motion and dynamic equation analysis of the actual system to achieve a good and accuracy results by reducing the error and minimize the disturbances. Simulation studies for a straightforward range of motion exercise were carried out, and experimental validation for the automated barrier with two DOF is performed to move the system forward and backward and avoid any obstacle on its path. The results obtained shows that the controller can track the desired position and trajectories for the barriers system motion, and adequately adapt the control parameters to the crowd conditions and the sensor and motor control performance.

Keywords: crowd, pedestrians, crowd control, riot control, simulation, control system, computed torque controller, barriers, barricades.

1. INTRODUCTION

Barriers have been used commonly in many places and for many functions such as demonstration, sports event, concerts and any political rallies. In these cases, the foremost goal is to control and prevent people from entering restricted or particular areas. In the wake of frequent unrest in many countries, the police are updating the crowd barrier, which is currently in use so that the system can work along with the approaches used to pacify and to disperse the unruly crowd [1].

Current barriers are not mobile, and thus prevent the police from implementing specific strategies for them to work effectively in cases where the crowd is becoming out of control. Otherwise, these static barricades sometimes become weapons themselves if people move it; also they can be dangerous if thrown, and can make the situation at the event so perilous, for both onlookers and police. Therefore, automated crowd control barriers can be used substantially during outdoor protests and demonstrations. These barriers are used to keep the general public, protesters, and the police safe during any events.

Citizens have the right to hold the assembly and demonstration, so the police have to reassess strategies and methods with appropriate equipment to ensure that this gathering/demonstration can be conducted in without disturbing the general public, however pedestrian safety is one of the biggest challenges facing the implementation of the principles of safe system [2], subsequently optimal solution for the crowd of pedestrians has to be selected based on a rational and comprehensive analysis.

The crowd is the study of how and where the masses are formed and moving above the critical density for more than one person per square meter, and this density can give the potential for overcrowding or personal injury to individuals and security [3].

This study presents the development of the automated pedestrian crowd-control barrier that consists of 2-DOF link system including one active prismatic joint and one revolute joint respectively. An alternative approach based on planning trajectory is used to model and simulate the Automated crowd barrier in computer simulation and real-time. The main advantages of the automated barrier system are that allow a broad range of movement in a backward and forward direction depending on the movement of crowd people. So if the crowd start moving forward, then the barrier will move back the same distance of the crowd movement, and when the crowd moves backward, the barrier will start move forward to follow the crowd until origin then stop. Otherwise, if there is any obstacle on the barrier path while moving backward, the barrier will stop. This system help in reducing the time and labor spent in setting parameter around demonstration area as a result of automated operation, moreover the automated barrier system aid to enhance the safety of general public during demonstration and events.

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The system will be implemented to control the dynamic barriers using Arduino controller with MATLAB Simulink in addition to sensory-motor control. So the design components and variables can be tested in a simulation environment and then adopted for the final layout. Consequently, this work proposed a movement model of crowd mobile barriers to investigating movement behavior of crowd barriers. This barriers model contains collision avoidance functions and the cases of trajectory planning decision of the barrier taking one's inertia into account. An ultrasonic sensor attains collision avoidance for sensing the distances between barrier and crowd.

The work presented in this project provides an analytical study, simulation, and experimental implementation of movable barrier system with two degrees of freedom (DOFs) that carries one prismatic joint for translational movement and one revolute to perform the rotation for this praxis in a real environment. So this project is concerned with developing pedestrian dynamic barriers model that can be used in the control and the study of crowd behavior in normal and panic conditions.

The rest of the papers are organized as follows: Section 2 describes the barrier kinematics model; Section 3 gives the control technique to control the 2-DOF barrier mechanism, while the fourth section is the trajectory tracking and results. The last two parts concludes the future work and conclusion.

2. THE KINEMATICS MODEL OF THE 2-DOF BARRIER

A. The forward kinematics

The proposed model of the automated pedestrian crowd-control barrier consist of two active DOF: one prismatic joint and one revolute joint well-arranged by design in a kinematic chain to generate two link lengths as shown in Figure-1. The prismatic joint allows the linear translational actuation forward and backward for the barrier while the revolute joint provides the rotational motion.

The representation of Denavit-Hartenberg for modeling the system links and joints can be used to get the solution of kinematics, beside to represent transformations in any coordinates for any system configurations as shown in Figure-2. The movement action between the two joints variables and the orientation and position of the barrier's response is derived from the four D-H parameters which given in Table-1. The four parameters $a_i, \propto_i, d_i, \theta_i$ are generally known as the link length, link twist, link offset, and joint angles respectively [4].

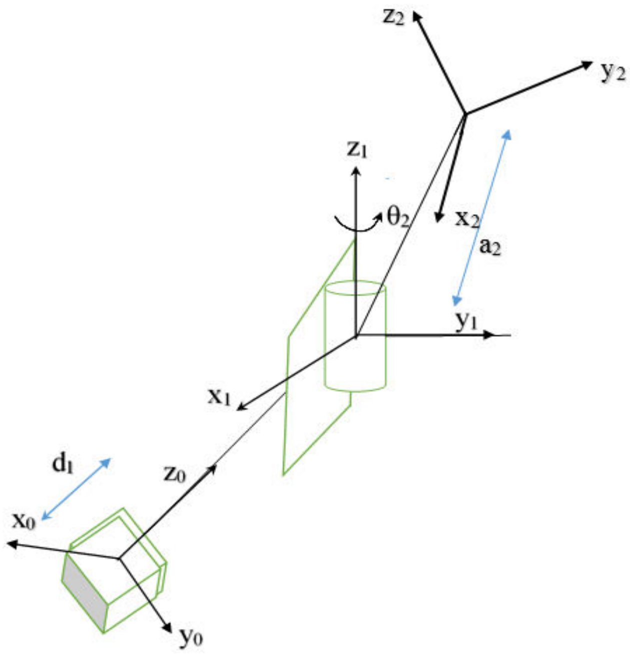

Figure-1. Barrier kinematic model.

Table-1. DH parameters of the barrier system.

Link	a_i	α_i	d_i	θ_i
1	0	90	d_1	0
2	a_2	0	0	θ_2

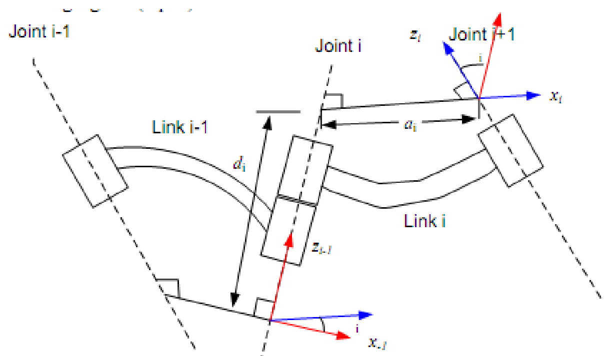

Figure-2. The Denavit-Hartenberg convention.

Using the general form of the D-H homogeneous transformation matrix from joint 1 to joint 2 that given by (1) [5] to derive the corresponding transformation a matrices (Equation 2)$^{i-1}_{i}T$ =

$$\begin{bmatrix} c\theta_i & -s\theta_i c\alpha_i & s\theta_i s\alpha_i & a_{ic\theta_i} \\ s\theta_i & c\theta_i c\alpha_i & -c\theta_i s\alpha_i & a_{is\theta_i} \\ 0 & s\alpha_i & c\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

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$$\left.\begin{array}{l} A1 = {}^0_1T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & d1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \\ A2 = {}^1_2T = \begin{bmatrix} c\theta_2 & -s\theta_2 & 0 & a2c\theta_2 \\ s\theta_2 & c\theta_2 & 0 & a2s\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{array}\right\} \quad (2)$$

The homogenous transformation matrix that relates the frame 2 of the barrier device to frame 0 obtained by multiplying the individual link transformation matrices in (2) which derive from the parameters in D-H table is given by (3).

$${}^0_2T = \begin{bmatrix} c\theta_2 & -s\theta_2 & 0 & a_2c\theta_2 \\ 0 & 0 & -1 & 0 \\ s\theta_2 & c\theta_2 & 0 & d_1 + a2s\theta_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

The forward kinematics equation is easily derived from (3) as:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} a_2c\theta_2 \\ 0 \\ d_1 + a2s\theta_2 \end{bmatrix} \quad (4)$$

The solution of the forward kinematics equation leads to find the location and orientation of the automated barrier system with the relation of the links position in terms of specifying the value of the joint variables θ_2, and d_1 in addition to a_2.

B. The inverse kinematics

The inverse kinematic of the 2-DOF barrier system is to determine the value of each joint in order to place the system at a desired position and orientation [6, 7]. Whilst the barrier platform has only 2-DOF with single link length, the solution of the inverse kinematics will be quite simple, and can derived from the forward kinematic equations that given in Equations (3) and (4). Assuming the desire position and orientation to place the barrier system by given the n, o, a, p vectors as:

$${}^0_2T = \begin{bmatrix} c\theta_2 & -s\theta_2 & 0 & a_2c\theta_2 \\ 0 & 0 & -1 & 0 \\ s\theta_2 & c\theta_2 & 0 & d_1 + a2s\theta_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

By Equating the elements (1, 1), (3, 1), and (3, 4) of the two matrices, get the values of $\theta_2 \& d_1$ as:

$$\left.\begin{array}{l} \theta_2 = \tan^{-1}\frac{n_z}{n_x} = \mathrm{Atan}\,2(n_z, n_x) \\ d_1 = p_z - a2n_z \end{array}\right\} \quad (6)$$

C. The velocity kinematics: Jacobian

The Jacobian matrix relates the coordinate system of the task space linear and angular velocities of the robot application when its move in term of joint velocities. For the proposed barrier 2-DOF platform, the non-singular Jacobian matrix of the barrier system is derived as:

$$J = \begin{bmatrix} J_v \\ J_w \end{bmatrix} = \begin{bmatrix} 0 & -a2s\theta_2 \\ 0 & 0 \\ 1 & a2c\theta_2 \\ 0 & 0 \\ 0 & -1 \\ 0 & 0 \end{bmatrix} \quad (7)$$

Where Jv and Jw are the non-singular linear and angular components of the Jacobian.

D. Barrier model workspace

The 3-dimensional reachable workspace of the automated barrier model depending in its configuration and the links size and joints angle is shown in Figure-3, using the forward kinematics equation given in (4).

The pedestrian crowd barrier platform consist of one revolute joint with possible ranges of motion given as $0 \leq \theta 2 \leq \frac{45\pi}{180}$, and a prismatic joint with a total possible range of displacement, d_1, from 0 to 1.5m.

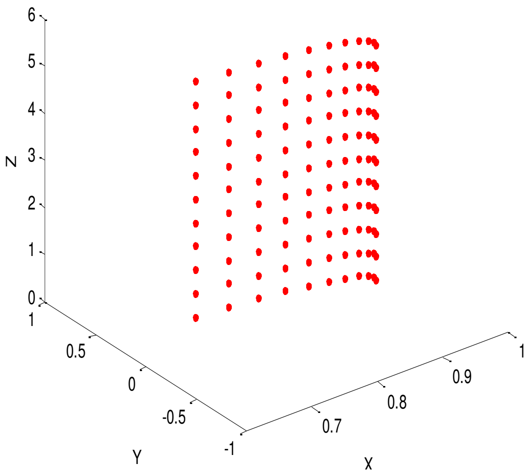

Figure-3. The barrier reachable workspace in 3-D space.

3. THE CONTROL TECHNIQUE

A. The barrier dynamics

It is necessary to derive the dynamic equations to control the automated barrier system motion in relation with the environment of the crowd people. Using the Euler-Lagrange formula and assuming the external interactive forces are zero, the barrier system dynamic equation can be written as:

$$\tau = M(q)\ddot{q} + I_{act}\ddot{q} + C(q,\dot{q})\dot{q} + G(q) \quad (8)$$

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Where $M(q)$ represents the 2x2 inertia matrix of the robotic barrier platform; $N(q, \dot{q})$ represents the nonlinear centrifugal and Coriolis acceleration terms, and the vector of gravity force at the two joints; $F(\dot{q})$ models the viscous and dynamic friction including the errors, disturbances and other uncertainties; and τ represent the 2x1 joint actuator toques.

B. PD-Computed torque control

The control technique adopted in this work is the computed torque control technique which has been used extensively in industrial applications, for robotics model control [6-10]. The computed torque control technique is based on the conception of the inner and outer-loop control design strategy which generate feed feedback linearization of the dynamic equation given in (8).

For the automated barrier system, suppose that a desired trajectory, $q_d(t)$, has been chosen for the barrier motion. To ensure trajectory tracking based on the joint variable, define an output or tracking error that given as:

$$e(t) = q_d(t) - q(t). \tag{9}$$

Getting the second derivative of (9) gives

$$\ddot{e}(t) = \ddot{q}d(t) - \ddot{q}(t). \tag{10}$$

Solving for $\ddot{q}(t)$ in (6) and substituting into equation (10) yields

$$\ddot{e}(t) = \ddot{q}(t) + M^{-1}(N + F - \tau). \tag{11}$$

From (9), defining the control input function, u,

$$u = \ddot{q}(t) + M^{-1}(N - \tau) \tag{12}$$

And the disturbance function as

$$w = M^{-1}F \tag{13}$$

By inverting the feedback linearization transformation (12), the computed-torque control law is defined as

$$\tau = (\ddot{q}_d - u) + N \tag{14}$$

where the control input, u, using a PD compensator can be chosen as

$$u = -K_d\dot{e} - K_p e \tag{15}$$

Then the overall control framework for the barrier is shown in Figure-4.

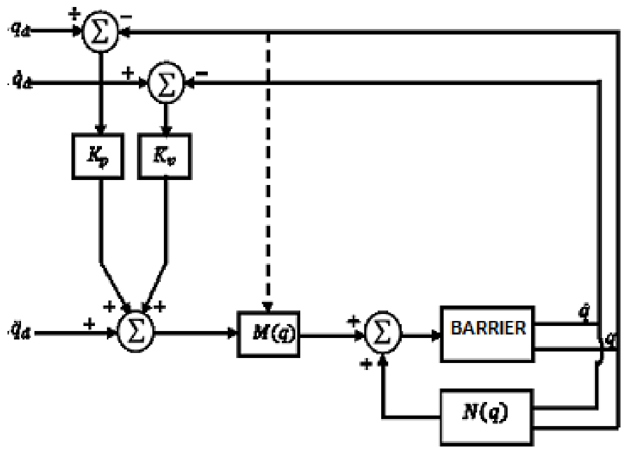

Figure-4. The barrier control framework.

4. SIMULATION RESULT AND TRAJECTORY TRACKING

To evaluate the performance of the overall barrier system, the following case of the task space desired position, velocity, and acceleration trajectories are selected and the simulation done over a simulation time of 10s.

A. Prismatic joint

For the prismatic joint at time = 1s, 5s, 10s, using the quadratic-order to plan trajectory, as follows:

$$q_1(t) = 0.27 - 0.28t + 0.005t^2. \tag{16}$$

$$\dot{q}_1(t) = -0.28 + 0.01t. \tag{17}$$

$$\ddot{q}_1(t) = 0.01. \tag{18}$$

B. Revolute joint

For the prismatic joint at time = 0.5s, 4s, 8s, using the quadratic-order to plan trajectory, as follows:

$$q_2(t) = -0.148 + 0.1545t - 0.00616t^2. \tag{19}$$

$$\dot{q}_2(t) = 0.1545 - 0.0123t. \tag{20}$$

$$\ddot{q}_2(t) = 0.0123. \tag{21}$$

These equations allow determining the position, velocity and acceleration for the barrier control system.

Figure-5 shows the trajectory tracking of the desired joint position for the prismatic joint.

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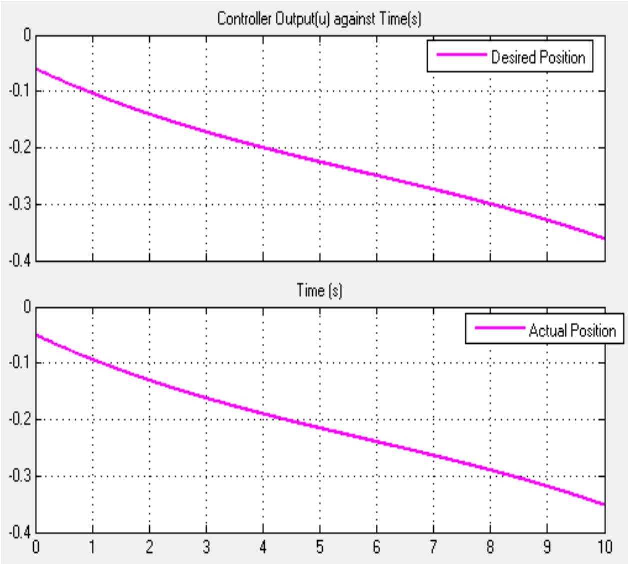

Figure-5. Position tracking.

Figure-6 shows the trajectory tracking of the desired joint velocity for the revolute joint, while Figure-7 shows the trajectory tracking of the desired joint acceleration for the prismatic joint.

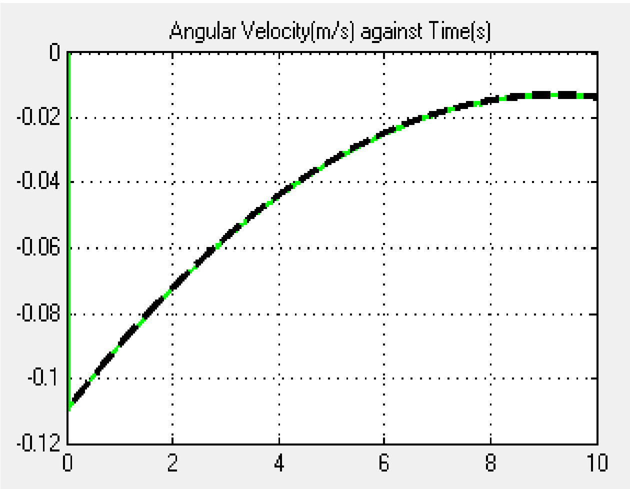

Figure-6. Velocity tracking.

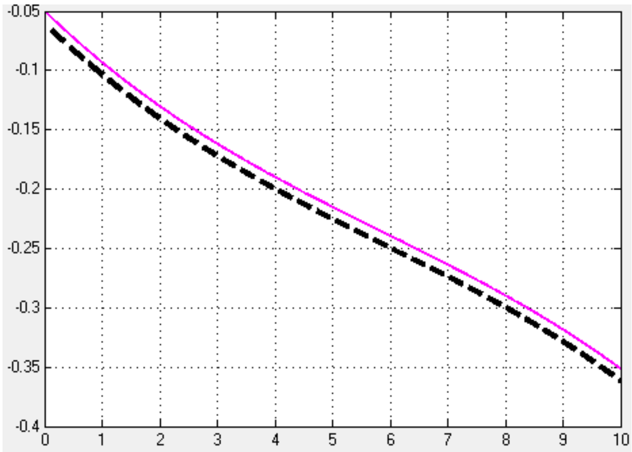

Figure-7. Joint acceleration.

5. FUTURE WORKS

Since the proposed work has been developed for the pedestrian barrier system to be movable and dynamic with a scalable design, the work will be drawn up to build serial-link barriers system with multi-DOF. The multi-DOF automated pedestrian barriers system can interact with the crowded environment to avoiding any collision and provide the protection for the public people and the security men of any risks during the confrontation.

6. CONCLUSIONS

The Paper proposed an automated pedestrian crowd-control barrier system with 2-DOF based on a closed-loop feedback control using PD computed torque control to get the best performance of the barrier model. This automated barrier helps in providing a safe area in the crowded environment to avoiding collisions during any event. Forward kinematic analysis have been presented to get the position and orientation of the barrier system, in addition to inverse kinematics to determine the value of each joint in order to place the system in a desired position and orientation. And also, the Jacobian, which relates the coordinate system of the linear and angular velocities of the barrier platform when its move in term of joint velocities. Furthermore, the analysis of the dynamic equations that help to build the control technique planning trajectory is provided by suggesting some cases to control a particular current crowd situation using Computed Torque Controller (CTC). The result of the trajectory tracking is clearly presented which compare the desired and actual tracking for the joints position and velocities.

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