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# Fuzzy Logic Control for Balancing a Two-Armed Inverted Pendulum

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Abstract The unicycle robot is an activated model with only one wheel, which ensures its safety. Researchers were particularly interested in the unicycle robot because of its great robustness, which allows it to travel around without colliding with the ground. The inverted pendulum having two arms is modelled using a mathematical representation based on the Lagrangian formulation in this work, which embodies our concept of the unicycle robot. The fuzzy logic control algorithm will then be used to produce a high level of solidity for this system.

Keywords Stability, Fuzzy logic, Lagrangian, Inverted pendulum.

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## 1. Introduction

The utilization of mobile robots in a variety of applications turns out to be more common continuously. The most challenging difficulty we will face today when employing a mobile robot is navigating through varied locations, regardless of the boundaries. Various mobile robot concepts consider robot form restrictions. This introduction illustrates the evolution and advancement of mobile robots from many wheels to a single wheel.

Generally speaking, mobile robots have multiple ground contact points, which results in several issues, such as the slip phenomenon. Thus, scientists are interested in reducing these contact points. [1], Maciej Trojnacki investigated the dynamics modeling of four-wheeled robots by characterizing the kinematic structure of the robot and presenting this device in three situations.

Concerning the three wheeled mobile robots, [2] mainly focused on modeling and control of a back wheel drive tricycle robot's movements when it came to three-wheeled robots. [3] portrayed the construction of a multi-robot task allocation technique using the fuzzy logic model.

In terms of two wheeled robots, [4] focused on a bike model that used a virtual holonomic constraint strategy to enable this model to navigate a rigorously arched bend with limited roll point and speed. Likewise, [5] designed a dynamic model of a two-wheeled vehicle and used control calculations to examine the model's stability.

Furthermore, [6] Azadeh Kheirandish portrayed the activity of an electric bike model managed by a power device while proposing a new figuring technique based on a fluffy intellectual guide that has the advantages of controlling and balancing out the model.

Lastly, the robot with only one wheel is a device that is able to move in various regions utilizing just one unique contact point, which has inspired experts to conduct research on this model. [7] built a balance bar-equipped unicycle robot and provided a versatile model based on an appeal formula. According to

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the modeling results, the model could become stable in a short time. [8] also posited a unicycle robot with a response wheel and built a working model using numerous electronic components to develop a self-governing machine. Equally important, [9] relied on the wheel's response to attain roll angle stability by rotating the disc to generate motion. The wheeled robot is utilized to achieve pitch angle balance, turning the wheel in all directions. Many control techniques, however, have been presented to stabilize the unicycle robot. Several studies, however, have used linear controllers, like the PID controller and the LQR [9; 10; 11], as well as nonlinear controllers, namely sliding mode controllers and backstepping controllers [7; 1]. To stabilize 5 degrees of freedom Spherical Inverted Pendulum, [13] proposed linear and nonlinear control algorithms. Intelligent controls, like the ItagakiSugeno technique by fuzzy logic [14; 15], were also used for the robot.

In this paper, we aim to introduce a unicycle robot prototype by first modeling a two-armed inverted pendulum, the system was then improved by combining other elements, and finally the arms will be replaced with a gyroscope.

As previously stated, applying perturbation $\tau$ to the two arms resulted in a rotation of the arms $\alpha$ and $\beta$, as well as the oscillation of the pendulum angle $\theta$ around its point of equilibrium. To maintain balance in the device, the fuzzy logic control technique will be suggested and modeled.

## 2. Mathematical Representation

Once a force is applied at the arms level, the two-armed inverted pendulum rotates, with the angles between both arms remaining fixed at 120 degrees during their revolution. The diagram below depicts our model conceptualization:

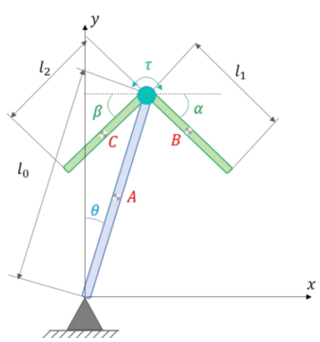


Figure 1. The two-armed inverted pendulum system.

The technical specifications for using this system are shown in the table below:

We can use the time derivate in the potential and kinetic energy formulations as follows:

The kinetic energy is represented as:

$$E_c = \frac{1}{6}(M+m)L^2\dot{\theta}^2\frac{1}{6}ml^2\dot{\alpha}^2 + \frac{1}{6}ml^2\dot{\beta}^2 + \frac{1}{2}mlL\dot{\theta}\dot{\alpha}\cos(\theta+\alpha)$$
$$-\frac{1}{2}mlL\dot{\alpha}\dot{\beta}\cos(\alpha+\beta) \quad (1)$$

Table 1. The dimensions of the system.

| Variables | Description |
|---|---|
| M | The mass of the inverted pendulum. |
| m | The mass of each arm. |
| l | The length of each arm. |
| L | The length of the pendulum. |
| g | the gravity constant 9.81 |
| $\theta$ | The angle of rotation of the inverted pendulum. |
| $\alpha$ | The angle of rotation of the first arm. |
| $\beta$ | The angle of rotation of the second arm. |
| $\tau$ | Applied perturbation on the two arms |

The potential energy is given by:

$$E_p = (\frac{1}{2}.M + 2m).L.g.cos(\theta) - \frac{1}{2}m.l.g.cos(\alpha) - \frac{1}{2}m.l.g.cos(\beta) \quad (2)$$

As seen below, the Lagrangian can be calculated by:

$$\begin{cases} \frac{d}{dt}(\frac{\partial \mathcal{L}}{\partial \theta'}) - (\frac{\partial \mathcal{L}}{\partial \theta}) = 0 \\ \frac{d}{dt}(\frac{\partial \mathcal{L}}{\partial \alpha'}) - (\frac{\partial \mathcal{L}}{\partial \alpha}) = \tau_\alpha \\ \frac{d}{dt}(\frac{\partial \mathcal{L}}{\partial \beta'}) - (\frac{\partial \mathcal{L}}{\partial \beta}) = \tau_\beta \end{cases}$$

Eq 1 :

$$(M.l^2 + J_1) + m(4l^2\ddot{\theta} + l^2\ddot{\alpha}cos(\theta+\alpha) - l^2\dot{\alpha}^2 sin(\theta+\alpha)) + 4ml^2\ddot{\theta} - m.l^2\ddot{\beta}cos(\theta+\beta) - ml^2\dot{\beta}^2 sin(\theta-\beta) - (M+4m)glsin\theta = 0 \quad (3)$$

Eq 2 :

$$(\frac{l^2}{4} + J_2)\ddot{\alpha} + ml^2\ddot{\theta}cos(\theta+\alpha) - ml^2\dot{\theta}^2 sin(\theta-\alpha) + \frac{m}{2}glsin\alpha = \tau_\alpha \quad (4)$$

Eq 3 :

$$(\frac{l^2}{4} + J_3)\ddot{\beta} - ml^2\ddot{\theta}cos(\theta-\beta) - ml^2\dot{\theta}^2 sin(\beta-\theta) + \frac{m}{2}glsin\beta = \tau_\beta \quad (5)$$

## 3. Fuzzy Logic For The Two-Armed Inverted Pendulum

Fuzzy control is an intelligent control technique that tries to solve control problems by relying only on expert knowledge to solve them. Fuzzy logic makes it possible to make the link between numerical modelling and symbolic modelling, which facilitates industrial developments from very simple algorithms for translating symbolic knowledge into a digital entity and vice versa. It has the advantage of using simple linguistic rules making it easy to translate the know-how of an expert to answer a specific problem.
Many researches have established that fuzzy logic control is capable of measuring the angular velocity and angle of inclination of the pendulum while calculating the force to be applied at each instant to maintain the pendulum in equilibrium.
The below figure illustrates the block diagram of fuzzy logic controller:

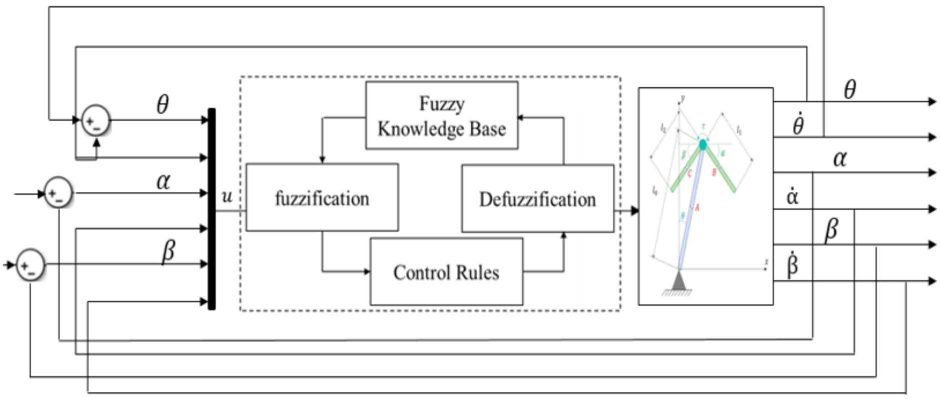


Figure 2. Fuzzy logic controller block diagram.

3.1. Mamdani:

The fuzzification step consists of defining fuzzy sets for the input and output variables. For each of these variables, the controller receives as input variables errors for the angles of the pendulum and for their angular velocities. A combination of five linguistic fuzzy values, defined by a Triangular shaped membership function, describes each of the specified input variables.

The figure 3 represents the mamdani membership functions for the angle $\theta$:

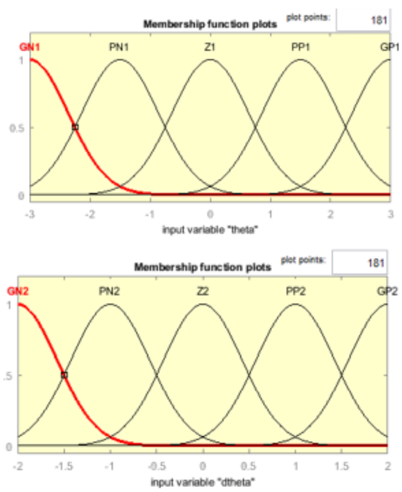


Figure 3. The membership functions for the angle $\theta$ .

3.2. Results:

After implementing the fuzzy logic control, the two-armed inverted pendulum oscillates as illustrated in the figures 2, 3 and 4.
The simulation results clearly show that the fuzzy logic controller compels the inverted pendulum to converge to the desired position within [0; 30] s in the figure 4, while, the two arms stay oscillate as shown

in the figure 5 and 6.
As a result, it's easy to see the quick response and good stability surrounding the equilibrium point.

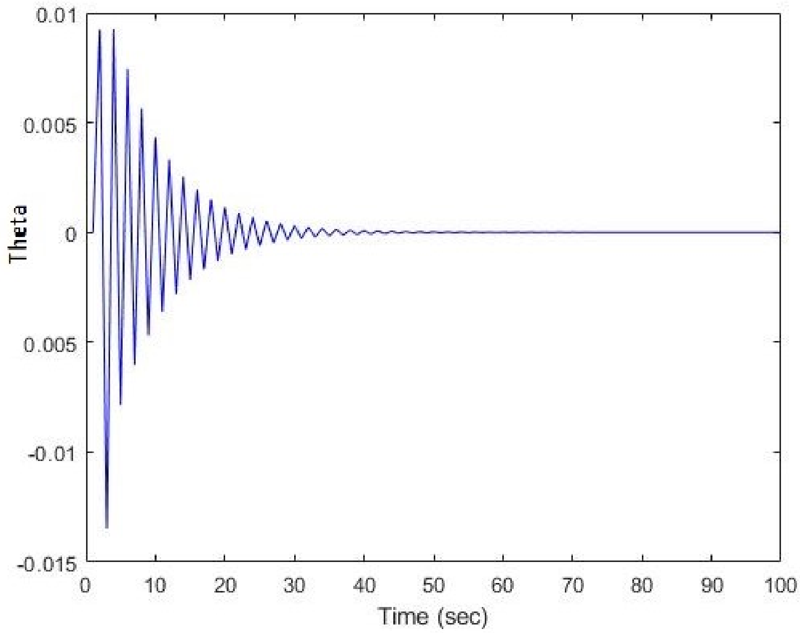


Figure 4. Fuzzy logic controller for the inverted pendulum.

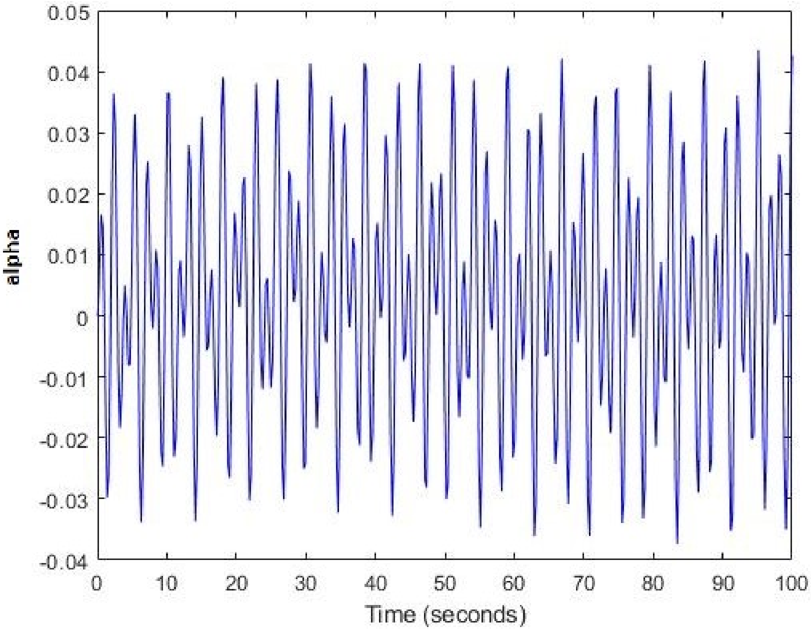


Figure 5. Fuzzy logic controller for the first arm.

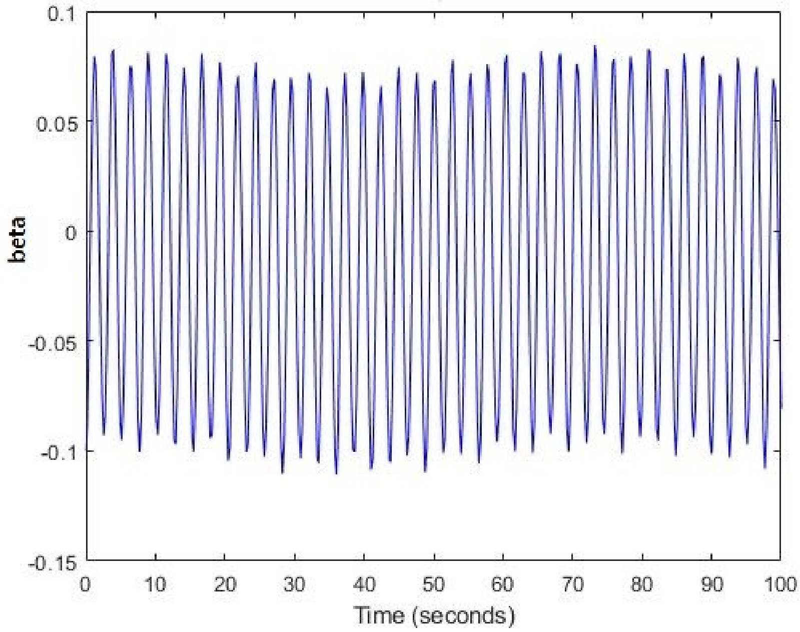


Figure 6. Fuzzy logic controller for the second arm.

## 4. Conclusion

We present a nonlinear dynamic model of a two-armed inverted pendulum spinning on Oxz repair in this paper. The lagrangian formulation was used to create the mathematical equations, and the fuzzy logic method was used to ensure its stability. The outstanding performance and effectiveness of this nonlinear technique were confirmed by simulation results.

## REFERENCES


1. Maciej Trojnacki: Dynamics Model of a Four-Wheeled Mobile Robot for Control Applications – A Three-Case Study (Springer International Publishing Switzerland 2015 D. Filev et al. (eds.), Intelligent Systems'2014, 99 Advances in Intelligent Systems and Computing 323,).
2. Y. YAVIN : Navigation and Control of the Motion of a Back Wheel Drive Tricycle (Mathl. Comput. Modelling Vol. 25, No. 11, pp. 23-29, 1997).
3. P.Chand, D.Carnegie , in: Development of a reduced human user input task allocation method for multiple robots, proceedings of Robotics and Autonomous Systems 60 (2012) 1231–1244.
4. L.Consolini , M.Maggiore ,in: Control of a bicycle using virtual holonomic constraints, proceedings of Automatica 49 (2013) 2831–2839.
5. M. Garziad, A. Saka ,in: A Comparative Assessment between LQR and PID Strategies in Control of Two Wheeled Vehicle, International Journal of Engineering Research in Africa, Vol: 43, pp: 59–70.
6. A.Kheirandish, F.Motlagh, N.Shafiabady , M.Dahari,A.Khairi Abdul Wahab,in: Dynamic fuzzy cognitive network approach for modelling and control of PEM fuel cell for power electric bicycle system,Proceedings of Applied Energy 202 (2017) 20–31.
7. L.Guo, K.He, Y.Song, in: Design of the Sliding Mode Controller for A Kind of Unicycle Robot, Proceedings of the IEEE International Conference on Information and Automation Ningbo, China, August 2016.
8. G.Pereira, in: Modeling,Construction and control of self-balancing unicycle robot,Sao Paulo,2017.
9. M.Rosyidi, Eko.Binugroho, E.Charel , R.Sanggar Dewanto, D.Pramadihanto, in: Speed and Balancing Control for Unicycle Robot, proceedings of 2016 International Electronics Symposium (IES).
10. Manukid Parnichkun, in : Development and control of a unicycle robot with double flywheels www.elsevier.com/locate/mechatronics 2016.
11. Gong Daoxiong, Pan Qi, Zuo Guoyu and Deng Wenbo, in: LQR Control for a Self-balancing Unicycle robot, World Congress on Intelligent Control and Automation,2012.

12. Vallejo-Alarcón, C.Linares, V.Villa, in: Unicycle-Type Robot and Quadrotor Leader-Follower Formation Backstepping Control, proceedings of IFAC-PapersOnLine Volume 48, Issue 19, 2015, Pages 51-56.
13. S.Krafes, Z.Chalh, A.Saka, in: Backstepping Controller Design for a 5 DOF Spherical Inverted Pendulum, International Journal of Engineering Research in Africa , Vol. 41, pp 37-50
14. O.Castillo, L.Aguilar, S.Cardenas, in: Fuzzy Logic Tracking Control for Unicycle Mobile Robots, Engineering Letters, 13 : 2 (Advance online publication: 4 August 2006).
15. J.Xin Xua,Z.Guoa,T.Leea,in: Synthesized design of a fuzzy logic controller for an underactuated unicycle, proceedings of Fuzzy Sets and Systems 207 (2012) 77–93.