

# Chapter 35

## Position and Tilt Control of Two-Wheeled Robot (TWR): A Neuro-Fuzzy Approach

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### ABSTRACT

*This paper presents a fuzzy based adaptive control approach for stabilization of Two wheeled robot (TWR) system. The TWR consists of a robot chassis mounted on two movable wheels. The objective is to stabilize the proposed system within desired time, minimum overshoot and at desired location. The data samples collected from simulation results of fuzzy controllers were used for training, tuning and optimisation of an adaptive neuro fuzzy inference system (ANFIS) controller. A Matlab Simulink model of the system has been built using Newton's second law of motion. The effect of shape and number of membership functions on training error of ANFIS has also been analysed. The designing of fuzzy rules for both fuzzy and ANFIS controller were carried out using gbell shape memberships. Simulations were performed which compared and validated the performance of both the controllers.*

### INTRODUCTION

Two wheeled robot (TWR) is one of the configuration of humanoid robot which is capable of moving and balancing on its two wheels. It comprises of a robot body or chassis attached to a pair of rotating wheels driven independently by motors (Kim and Kwon, 2015; Genichi, 2016). TWR is a mechanical system which is highly chaotic in dynamics (Ouannas, 2017a, 2017b). It has got three degree of freedom which enables it to rotate on a particular location. It is very useful for areas having complex layout and can enter places where conventional robot cannot (Cai and Ruan, 2011). Dynamics of TWR shows that it is a highly under-actuated system, inherently open loop, unstable and highly nonlinear (Muhammad et al., 2013). It belongs to a category of inverted pendulum system and is an area of research for future

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locomotion of humanoid robots (Miller, 2008). Inverted pendulum system has got two inherent equilibrium points i.e. a stable and unstable equilibrium points (Vaidyanathan et al., 2017a, 2017b). Its configuration resembles behavior of unstable equilibrium posture of inverted pendulum system (Pham et al., 2017). The additional degree of freedom enhances the complexity and intricacy of proposed system (Kim et al., 2005). Past literature suggests that TWR has been great source of motivation for researchers in the past few years (Azar & Vaidyanathan, 2015a, 2015b, 2015c; Azar & Zhu, 2015; Zhu & Azar, 2015). A method based on adaptive fuzzy control of two-wheeled upright robot has been proposed by Ruan et al. (2009). The results illustrated that proposed technique not only controls the system for large initial angles but also improves its stability. In another study by Ruan et al. (2008), a method for controlling TWR through reinforcement learning and fuzzy neural networks (FNN) has been proposed. The proposed approach was able to control continuous states while maintaining balance of robot in a short time.

Wu and Zhang (2011) considered a pole placement feedback control and fuzzy logic control for a two-wheeled self-balancing robot. The kinetic equations were derived based on Newton dynamic mechanics theory. The simulation results showed better performance of fuzzy controller compared to other controllers. Wen et al. (2013) studied the balance control of a two-wheeled robot based on fuzzy and Proportional-integral-derivative (PID) control. The authors further implemented the control circuit to a real robot model. In a study by Watanabe et al. (1993), a fuzzy gaussian neural network (FGNN) controller for controlling speed and azimuth of mobile robot has been discussed. The learning controller consisted of two FGNNs based on independent reasoning and connection weights. Bature et al. (2014), proposed three different control techniques i.e. fuzzy logic, linear quadratic controller (LQR) and PID for real-time control of a two-wheeled mobile robot. The results showed better performance of fuzzy compared to other two techniques.

Ahmad et al. (2011) designed a two-level modular fuzzy controller for two-wheeled wheelchair. The model of standard wheelchair was developed and verified using Visual Nastran software integrated with Matlab. Miasa et al. (2010) incorporated ADXL330 accelerometer and two DC motors as sensors and actuators respectively for balance control of TWR. The authors designed a fuzzy control for testing the system in Matlab as well in Laboratory. Goher et al. (2010) investigated control of a TWR with a payload positioned at different locations along its intermediate body. Proportional-derivative (PD) and PD-fuzzy controllers were used for balancing the proposed vehicle. A novel flexible design of two wheeled vehicle was given by Almeshal et al. (2013). The system dynamics was derived using Lagrangian dynamic formulation. A PD-PID robust control approach was further applied for the stabilisation of the proposed system. In a study by Wu et al. (2012), a fuzzy PD control of a two-wheeled self-balancing robot has been proposed. The kinetic equations for the system were constructed using Newtonian dynamics and mechanics. The authors described a real-time control platform of the proposed system.

## **MATHEMATICAL MODEL OF TWR**

The mathematical equations of motion for TWR has been derived using Newton's second law of motion. A schematic view of TWR is shown in Figure 1. The system comprises of a robot chassis of length ( $2H = 0.1\text{m}$ ) and mass ( $M_c = 2.0\text{ Kg}$ ), mounted on a wheel of mass ( $M_w = 0.5\text{ Kg}$ ) and radius ( $r_w = 0.1\text{m}$ ). Force ( $F$ ), is required to drag the system horizontally against a friction force ( $F_f$ ) and gravity ( $g = 9.81\text{ m/s}^2$ ). The objective is to maintain the chassis vertically upwards while the wheels are stationary. The stable and unstable positions of the robot are clearly shown in the Figure 1. The various attributes which

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