Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 45 No.5
May 2024

Design and Development of an Automated Tilt Controller for Tilting 3-Wheeler

Albin K Joseph[1], Deivanathan R*
[1]Vellore Institute of Technology, Chennai
*Professor, Vellore Institute of Technology, Chennai

Abstract—A tilting three-wheeler is a type of vehicle with three wheels, where two wheels are situated in the front and one in the rear. In this configuration, the rear wheel serves as the driving wheel, and the steering mechanism is connected to it. What sets this type of vehicle apart is its unique ability to tilt its body and wheels in the direction of a turn. This tilting feature plays a crucial role in enhancing the stability of the vehicle, especially when navigating curves at higher speeds, allowing for safe and comfortable cornering. The focus of this study revolves around the design of a compact model of a tilting three-wheeler and the implementation of an automated tilting mechanism. The automated tilting system is under the control of an Electronic Control Unit (ECU), which coordinates various types of sensors, actuators, and controllers to facilitate the tilting functionality of the vehicle. This automated mechanism enhances the maneuverability and safety of the tilting three-wheeler, providing improved stability and control during cornering maneuvers

Keywords— tilting vehicle, rollover, controller, three-wheelers.

I.Introduction

Three-wheeled vehicles that tilt are a groundbreaking advancement in city transportation, providing a perfect mix of stability, maneuverability, and efficiency. Commonly known as "tilting trikes," these vehicles lean into turns like a two-wheeler but maintain the stability of a three-wheeled setup. This inventive design not only elevates the excitement of riding but also offers practical benefits such as better cornering and less space needed, making them excellent for navigating busy urban roads.

Figure 1.1 contrasts and compares the size of the tilting 3-wheeler with the vehicles of the masses. This helps to get a broad idea with regard to its dimensioning and design.

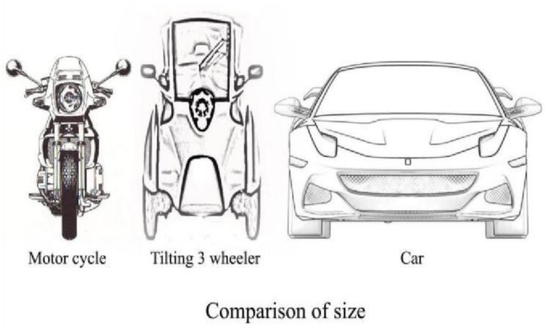

Fig 1.1: Tilting 3-wheeler size

As urban populations continue to grow and cities become more congested, the need for efficient and sustainable modes of transportation becomes increasingly apparent. Tilting three-wheelers offer a promising solution to this challenge, offering a compact and agile alternative to traditional four-wheeled vehicles.

The concept of a tilting vehicle is not new, with early prototypes dating back to the early 20th century. However, recent advancements in materials, engineering, and design have revitalized interest in this concept, leading to the development of modern tilting three-wheelers that are both practical and commercially viable.One of the key features of tilting three-wheelers is their ability to lean into turns, similar to a motorcycle. This tilting mechanism is achieved through a combination of sophisticated suspension systems and gyroscopic technology, allowing the vehicle to maintain stability while cornering at high speeds.

In addition to their maneuverability, tilting three-wheelers also offer other advantages over traditional vehicles. For example, they typically have a smaller footprint, making it easier to park and navigate through narrow streets. They are also more fuel-efficient, thanks to their lightweight construction and aerodynamic design.Overall, tilting three-wheelers represent a compelling option for urban transportation, offering a blend of stability, maneuverability, and efficiency that is well-suited to the demands of modern city living.

The design and development of an automated tilt controller for tilting three-wheelers represent a significant advancement in the field of urban mobility. This innovative technology aims to enhance the stability and safety of tilting three-wheelers by automating the tilting process, thereby improving the overall riding experience for users.

Tilting three-wheelers, with their unique ability to lean into turns like a motorcycle, offer a compelling solution to the challenges of urban transportation. However, the tilting mechanism requires careful control to ensure that the vehicle remains stable and balanced during cornering [1-4].

The automated tilt controller addresses this challenge by using sensors and actuators to detect the vehicle's speed, acceleration, and tilt angle, and adjust the tilt of the vehicle accordingly. This real-time adjustment helps to maintain stability and control, even in challenging road conditions or during sudden maneuvers.The development of an automated tilt controller for tilting three-wheelers involves a multidisciplinary approach, combining expertise in mechanical engineering, electronics, control systems, and software development.

At the centre of the system is a sophisticated control algorithm that processes data from the vehicle's sensors and calculates the optimal tilt angle for the current driving conditions. This algorithm takes into account factors such as vehicle speed, acceleration, steering input, and road conditions to determine the appropriate tilt angle for maximum stability and maneuverability.

The tilt controller also includes a network of actuators that physically adjust the tilt of the vehicle in response to the control algorithm's commands. These actuators are typically hydraulic or electric and are designed to provide smooth and precise tilt adjustments, ensuring a seamless and comfortable riding experience for the user.

One of the key challenges in designing an automated tilt controller is ensuring that it is both effective and safe. The controller must be able to react quickly to changing driving conditions, while also ensuring that the vehicle remains stable and balanced at all times.

Overall, the design and development of an automated tilt controller for tilting three-wheelers represent a significant step forward in the field of urban mobility, offering the potential to improve the safety, efficiency, and comfort of these vehicles for riders around the world [5-6].

Sindha et al. provided a comprehensive review of methodologies, control strategies, vehicle types, and mathematical models used in the development of automatic stability control systems for three-wheeler vehicles. Dandiwala et al. discuss the utilization of Direct Tilt Control (DTC) as a primary strategy for testing tilting vehicles, highlighting its efficacy in integrated tilt control systems. Berote at al utilize multi-body simulations to demonstrate a tilt control method for narrow-track three-wheeled vehicles, particularly during emergency lane change maneuvers.Karamuk et al. conduct simulations and experimental verifications on a three-wheeled electric vehicle, focusing on active control methods for stability enhancementVan Poelgeest et al. conducted a study on a three-wheeled tilting moped, focusing on the frequency of steering inputs and its relationship with vehicle stability. Tang et al. present the design of an integrated suspension tilting mechanism for narrow tilting vehicles, addressing the challenges involved in such suspension systems.

Berote et al. present a linearized model of the tilting vehicle system and optimize a new tilt controller in the frequency domain, contributing to the advancement of tilt control methods.Tang et al. introduce a new design consisting of a blade tilt adjustment automation system, track automation system, and maximum load protection system, enhancing the understanding of integrated suspension tilting mechanisms. Berote et al This study delves into the dynamic behavior of tilting vehicles and proposes an anti-tilting mechanism to enhance vehicle stability, particularly focusing on vehicles with narrow widths and low rollover risk [7]-10].

Karamuk et al. describe the design of a tilt controller and state feedback control law using a pole placement design technique, enhancing vehicle stability. Poelgeest et aldiscuss the objective of tilting standard passenger vehicles inward during cornering and provide a literature review on automotive tilting. Tang et al. presented a novel controller structure to enhance the response of Direct Tilt Control (DTC), improving the vehicle's tilting response at higher speeds Mohapatra et al. investigated the design and analysis of a type-II Fuzzy tilt controller, focusing on automated generation control Introduces a linearized model of tilting vehicle systems to optimize a new tilt controller in the frequency domain, enhancing vehicle stability. Theyreviewed the use of Direct Tilt Control (DTC) as the primary strategy for testing tilting vehicles, emphasizing its effectiveness [11-13].

This study focuses on the development of an automated tilt controller for a three-wheeled vehicle. The controller utilizes an array of sensors, actuators, and a microcontroller to precisely adjust the vehicle's tilt in response to changing road conditions. The tilt controller operates in tune with the steer by wire and drive by wire technology.This advanced system is designed to enhance the vehicle's stability during cornering, ensuring optimal performance and safety.

By integrating this technology, the vehicle can dynamically adapt to different terrains, improving its overall handling and maneuverability. The automated tilt controller actively adjusts the vehicle's tilt angle, maximizing stability when navigating curves and bends. This innovative approach enhances the vehicle's safety and responsiveness, providing a smoother and more controlled driving experience.

Ii.**Experimental Investigation**

A. Maximum speed to avoid over-turning

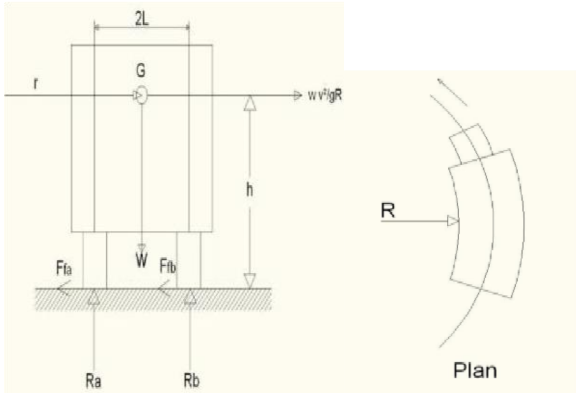

Fig 2.1 Motion of a vehicle on a level curved path

In fig.2.1, Ra and Rb are the support reactions at the front wheels of the vehicle whose center of gravity is at G and track width is 2L as shown. As the vehicle takes a tuen to the left ass shown, a centrifugal force acts away from the instantaneous center of turn, acting through G, at h from the base. By balancing the moments about point A and taking the equilibrium of vertical forces

$$R_a = \frac{W}{2}(1 - \frac{V^2h}{gRL})$$

As the equation suggests, as the radius of turn, Ra, approaches zero, the velocity, *V*, increases. If *V* is further increased, Ra becomes negative, leading to a risk of overturning. To prevent overturning, we must consider the limiting condition.$\frac{V^2h}{gRL}$>0

Therefore,**V=√(gRL/h)**

The equation indicates that an increase in the height of the center of gravity results in a decrease in the maximum velocity at which overturning can occur, establishing an inverse relationship between the height and the velocity. This relationship implies that vehicles with a higher center of gravity are more prone to overturning at lower velocities compared to vehicles with a lower center of gravity.

B. Motion of the tilted vehicle on a curved path

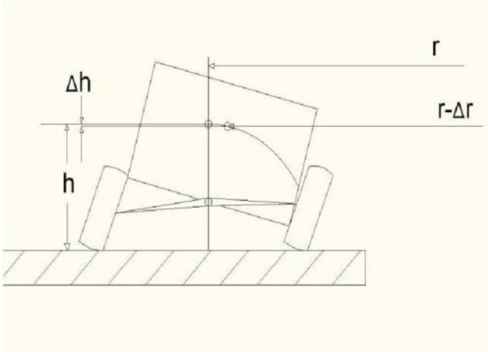

Fig 2.2 Motion of the tilted vehicle on a curved path

Figure 2.2 above illustrates that during a turn, the center of mass shifts towards the center of the curve, causing a decrease in the height of the center of gravity. This change in height is a crucial factor in determining the maximum velocity at which overturning can occur, as described by the formula V = √(gRL/h).

Reducing the value of "h," representing the height of the center of gravity, leads to an increase in the maximum overturning velocity. This principle serves as the basis for the design and construction of tilting three-wheelers, where the control unit is engineered to manipulate the center of gravity and optimize vehicle stability during turns.

Iii.Results And Discussions

A. Modeling and fabrication of tilting three-wheeler

Modeling of the tilting suspension system

The design and drafting of the suspension system and chassis for a narrow tilting vehicle were completed using CATIA V5 software. The suspension system comprises two upper and two lower arms, all hinged to a pair of T-sections in a linear configuration.Figure 3.1 pictorially shows the same

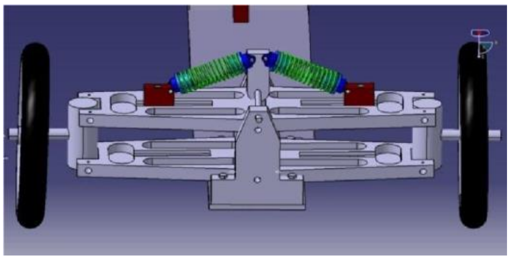

Fig 3.1 Model of front suspension in Catia v5

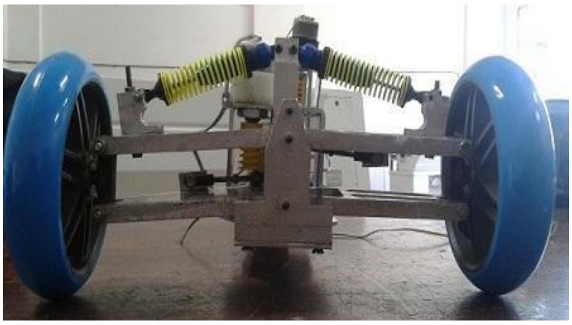

Fig 3.2 Model of front suspension

The front wheels of the vehicle are directly connected to the wheel hubs. To absorb sudden shocks and ensure a comfortable ride, two helical compression springs are attached to the left and right upper arms. These springs are interconnected in a way that distributes the load evenly between them as depicted in Figure 3.2.

In terms of size, the front wheels have a larger radius compared to the rear wheel, but they are narrower in widthand have a curved profile. The wheel hubs, which are connected to both the upper and lower arms, support the wheels.

A. Modelingandfabrication of chassis

The chassis is constructed from 3mm thick aluminum sheet, specifically designed to be narrower than conventional vehicles. This reduced trackwidth enables comfortable tilting of the vehicle without the chassis touching the ground. The chassis houses the batteries and the control unit necessary for the vehicle's operation. A 12V, 1.2A battery is provided to power the tilting mechanism and the controller unit.

The rear portion of the chassis accommodates the rear driving wheel and the steering system. The rear suspension is mounted between two sections of the chassis. The battery is positioned in the front section of the chassis for optimal weight distribution.To connect the rear wheel chassis to the main chassis, a hinge is used. A helical compression spring suspension is integrated into the hinged joint to absorb shocks and ensure a smoother ride.

B. Design and fabrication of the back-wheel drive and drive-by-wire steering mechanism

The rear wheel of the vehicle serves dual purposes as both the driving and steering wheel, making its design more intricate. The driving motor is directly connected to the wheel hub, ensuring efficient power transfer. Additionally, a geared spur gear is integrated into the wheel axis for speed measurement, facilitated by an inductive proximity sensor. This sensor generates a pulse for each tooth passing in front of it, allowing the microcontroller to calculate the vehicle's speed accurately.

To steer the vehicle, a steer-by-wire mechanism is employed, eliminating the need for a physical connection between the steering wheel and the wheels. Instead, a motor is used to control the steering, with its operation regulated by a potentiometer-based controlling unit. This unit manages both the driving and steering mechanisms. For enhanced torque and stable control, a worm and worm gear setup is utilized in the steering mechanism. Figure 3.3 and Figure 3.4 pictorially give the top and the side views respectively.

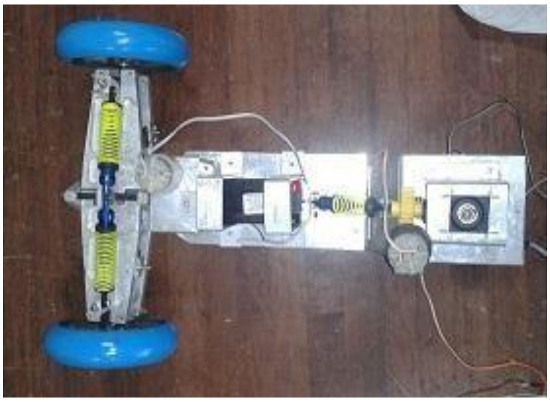

Fig 3.3 Top view of the tilting vehicle

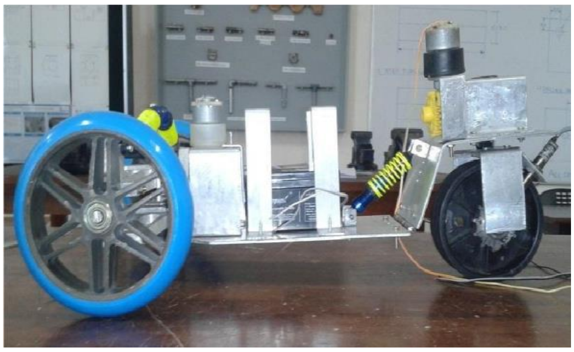

Fig 3.4 Side view of the tilting vehicle

C. Design and fabrication of tile control mechanism

Tilting mechanism consists of an electric dc motor, pair of worm and worm gear, pair of adjustable links, and a small 6 mm shaft with 20 mmx 3 mm bigger diameter disc at the end. The 6 mm shaft is fixed through a bearing with T-structure of the tilt suspension. The two adjustable links connect two lugs on the 20mm disc with the upper and lower arm on the left and right side respectively of the tilting suspension.

The knob of the 5 kilo ohm variable potentiometer is inserted through a hole at the small end of the shaft and glued into it . This potentiometer act as the tilt angle sensor. The worm and worm gear connect this shaft to the dc motor which actuates the tilt mechanism.

Fig. 3.5 shows the flow chart for tilt controller implementation. Ideally, let the tilt angle when the vehicle is running normally is Ɵ. As the user gives the steering effort, it is received by the controller and it calculates a desirable tilt angle in accordance to an established relation between the steering angle and tilt angle. The tilt sensor monitors the tilt angle and it is compared to the desired value to generate an error signal, which is subsequently reduced to zero by the main controller. It can differentiate positive and negative tilt about the right or left side of vehicle.

D. Design and fabrication of circuits for different sensors and actuators

The controller for the vehicle is a sophisticated circuit comprising a microcontroller, sensors, actuators, and other supporting components. At

Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 45 No.5
May 2024

its core, the microcontroller is a high-performance Atmel 32A device, featuring 32KB of programmable flash memory, 2KB of SRAM, and 1KB of EEPROM. Additionally, it includes an 8-channel 10-bit A/D converter. This microcontroller operates at a speed of 16 MIPS at a frequency of 16 MHz and requires a voltage input between 4.5 to 5.5 volts.

The key features of this microcontroller are its high performance and low power consumption. It is based on the AVR RISC architecture, providing efficient processing capabilities for the vehicle's control system.

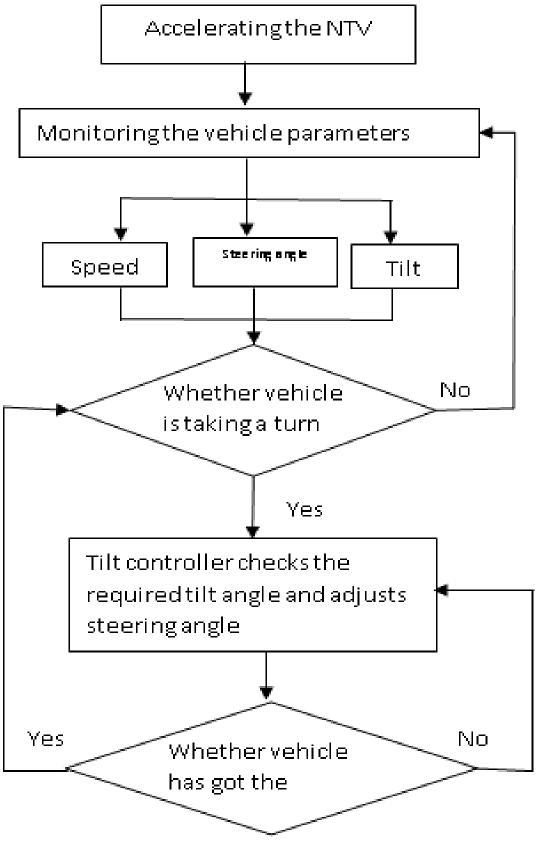

Fig.3.5 Flow chart of tilt control system

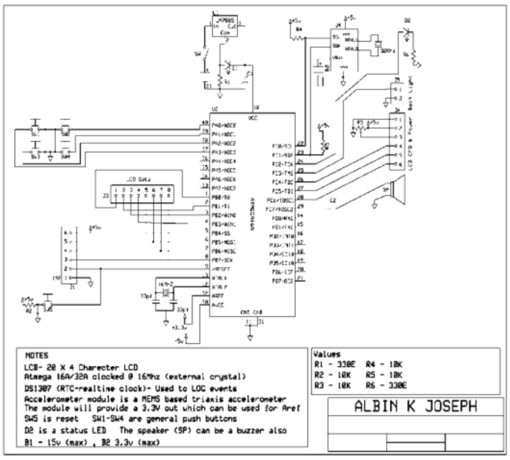

Fig 3.6 Circuit diagram for LCD interface

The controller comprises a microcontroller along with various supporting components such as resistors, crystals, capacitors, and potentiometers. The power supply is derived from the onboard 12V, 1.2A battery, regulated by a 7805 chip to provide a stable 5V supply to the controller. The circuit diagram for LCD display is represented in Figure 3.6.To control the DC motor actuators, two L293D driver circuits are incorporated into the controller.These circuits manage the direction and speed of the motors based on signals from the microcontroller.

For user interface and feedback, a JHD 204A 20x4 character green LCD module is employed. This display is used to present various status indicators such as speed, potentiometer ADC readings, and tilt angle, providing real-time information about the vehicle's operation.

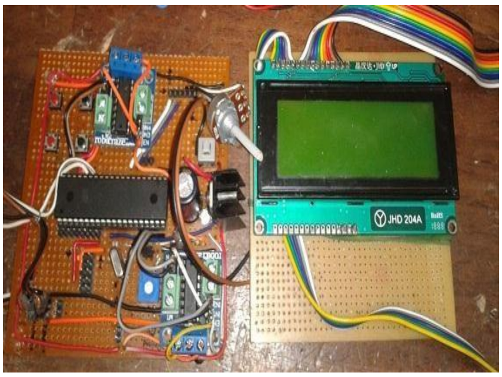

Fig 3.7 Controller unit circuit

The drive-by-wire system is operated by an additional Atmega 16 microcontroller-based remote control unit. This remote control features a potentiometer-based joystick, which serves dual functions for driving and steering. Each movement of the joystick sends unique commands from the remote controller to the main unit shown in Figure 3.7. These commands dictate the operation of the steering and drive motors accordingly.

The remote controller is equipped with an LCD as in Figure 3.8 that indicates the position of the joystick, providing real-time feedback to the user. It is powered by a 9V external battery, which is securely fixed onto the board. This setup allows for convenient and intuitive control of the vehicle from a distance.

Fig 3.8 Drive-by-wire remote control

E.Implementation and Testing

ISP 10 pin programmer is used for programming the AT mega 32 and AT mega 16 micro controllers. The codes programmed in the atmel studio 602 software and is burned through ISP programmer. The remote controller is programmed with functions like forward, reverse, left turning, and right turning. The status of the controller will show in the 20x2 LCD display. The main controller was programmed with different scenarios of the vehicle. The controller also communicate with the remote control, it will receive data from the remote controller and drives different actuators .

The different scenarios involves different status of the vehicle where speed, steering angle , and tilt angle changes. For example, the vehicle will not tilt when the wheel speed is less than 60 RPM even if the steering angle changes. A maximum of 30 degree tilt angle on either side of vertical was programmed to the controller. In the test case, the tilt angle changes are linearly related to the speed variation. The controller will always monitor the tilt of the vehicle with the tile angle sensor. Tilt control was performed with the help of a feedback system using the potentiometer tilt sensor and steer by wire system.

IV. Conclusion

The development process of the tilting three-wheeler prototype and its electronic control unit (ECU) involved a systematic approach to ensure optimal performance and safety. Initially, a detailed model of the vehicle was created, taking into account factors such as dimensions, weight distribution, and tilting mechanism design.

Next, the ECU was designed to interface with various sensors, including those for speed, tilt angle, and road conditions. Actuators were also integrated into the system to control the vehicle's tilt in response to the data collected by the sensors.

The programming of the ECU was a critical step, as it needed to consider different scenarios that the vehicle might encounter while in operation. This included scenarios such as sharp turns, uneven road surfaces, and varying speeds.

After the prototype was fabricated, extensive testing was conducted to validate the effectiveness of the ECU in controlling the vehicle's tilt. The results of these tests were promising, demonstrating that the ECU was able to successfully tilt the vehicle to reduce the height of the center of gravity. This, in turn, increased the overturning velocity of the vehicle, allowing it to take curves with more speed and confidence.

Overall, the development and testing of the tilting three-wheeler and its ECU represented a significant advancement in the field of urban mobility, offering a safer and more efficient alternative to traditional vehicles

References

[1] Electric tilting 3-wheel vehicle for sustainable urban Mobility by Manuele Bertoluzzo, Giuseppe Buja, Vittore Cossalter, Alberto Doria and Diego Mazzaro. University of Padova, Department of Electrical Engineering, Via Gradenigo 6/a, 35131 Padova, Italy.IEEE 2008.

[2] Experimental investigation of a narrow-leaning vehicle tilt stability control system by S. Kidane, R. Rajamani, L. Alexander, P. Starr, and M.

Donath.Proceedings of the 2007 American Control Conference Marriott Marquis Hotel at Times Square New York City, USA, July 11-13, 2007.

[3] The development of tilt-controlled narrow ground vehicles by J. Gohl, R. Rajamani, L. Alexander and P. Starr. Department of Mechanical Engineering University of Minnesota Minneapolis, MN 55455. Proceedings of the American Control Conference Anchorage, AK May 8-10,2002.

[4] Direct and steering tilt robust control of narrow vehicles by Lama Mourad, Fabien Claveau, and Philippe Chevrel. IEEE Transactions on Intelligent Transportation Systems, vol. 15, no. 3, June 2014.

[5] Development and experimental evaluation of a tilt stability control system for narrow commuter vehicles by Samuel Kidane, Rajesh Rajamani, Lee Alexander, Patrick J. Starr, and Max Donath. IEEE Transactions on Control Systems Technology, vol. 18, no. 6, November 2010.

[6] Modeling and verification of a diamond-shaped narrow-tilting vehicle by Jin-Chern Chiou and Chih-Liang Chen. IEEE/ASME Transactions on mechatronics, vol. 13, no. 6, December 2008.

[7] Sindha, Jignesh & Chakraborty, Basab & Chakravarty, Debashish. (2017). Automatic stability control of three-wheeler vehicles – recent developments and concerns towards a sustainable technology. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering. 232. 095440701770128. 10.1177/0954407017701285.

[8] Ankit Kumar Dandiwala, Basab Chakraborty, Debashish ChakravartyAn artificial neural network-based integrated tilt control system for narrow electric three-wheelers,Expert Systems with Applications, Volume 238, Part C,2024,121970,

[9] Berote, J & Darling, J & Plummer, Andrew. (2012). Development of a tilt control method for a narrow-track three-wheeled vehicle. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering. 226. 48-69. 10.1177/0954407011412311.

[10] Karamuk, M.; Alankus, O.B. Development and Experimental Implementation of Active Tilt Control System Using a Servo Motor Actuator for Narrow Tilting Electric Vehicle. *Energies* 2022, *15*, 1996.

[11] van Poelgeest, A., Edge, KA, & Darling, J. "Development of a Steer Tilt Controller for a Three Wheeled Tilting Vehicle." *Proceedings of the ASME 2007 International Mechanical Engineering Congress and Exposition*. *Volume 16: Transportation Systems*. Seattle, Washington, USA. November 11–15, 2007. pp. 149-156.

[12] Chen Tang, Ling He, Amir Khajepour,Design and analysis of an integrated suspension tilting mechanism for narrow urban vehicles,Mechanism and Machine Theory,Volume 120,2018,Pages 225-238.

[13] Ashok Kumar Mohapatra, Srikanta Mohapatra, Amruta Pattnaik, Prakash Chandra Sahu,Design and modelling of an AI governed type-2 Fuzzy tilt control strategy for AGC of a multi-source power grid in constraint to optimal dispatch,e-Prime - Advances in Electrical Engineering, Electronics and Energy,Volume 7,2024,100487,