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A Review on Mechanical Design of a Four Wheel Steering System

Vipin Singh
Department of Mechanical Engineering
Sagar Institute and Research & Technology
Bhopal, M.P,India
vipin91195@gmail.com

Sharad Sharma
Department of Mechanical Engineering
Technocrats Institute of Technology
Bhopal, M.P, India
shaggysharad@gmail.com

***Abstract*--In standard 2 Wheel Steering System, the rear set of wheels are always directed forward and do not play an active role in controlling the steering. While in 4 Wheel Steering System, the rear wheels do play an active role for steering, which can be guided at high as well as low speeds. Production cars are designed to under steer and rarely do them over steer. If a car could automatically compensate for an under steer/over steer problem, the driver would enjoy nearly neutral steering under varying operating conditions. Also in situations like low speed cornering, vehicle parking and driving in city conditions with heavy traffic in tight spaces, driving would be very difficult due to a sedan's larger wheelbase and track width. Hence there is a requirement of a mechanism which result in less turning radius. The aim of this paper is to study & analyze an improved driving assistance system which provides four wheel steering mechanism as well as Zero steer mode.**

Keywords- Steering System; 4WS; 2WS; Zero steer mode; Production cars;

I. INTRODUCTION

4 Wheel Steering System is employed in vehicles to achieve better maneuverability at high speeds, reducing the turning circle radius of the car and to reduce the driver's steering effort. In most active 4 wheel steering system, the guiding computer or electronic equipment play a major role, in our project we have tried to keep the mechanism as much mechanical as possible which can be easy to manufacturing and maintenance.

This paper focuses on a mechanically feasible & innovative design involving a double rack and pinion system for rear wheels enclosed within a casing, connected to the steering column by a combination of a bevel gear assembly & telescopic shaft. The movement of the rear wheels is done by the movement of the rear pinions which in turn move the newly designed spindle to achieve the required movement of the rear wheels.

A confined space is an area whose structure or contents that may present danger to the workers while perform job such as repair, service or maintenance. The poorly ventilated zone in the confined space will decrease the oxygen and increase concentration of hazardous volatile compounds such as Ammonia (NH3), Hydrogen Suphide (H2S) and Carbon Monoxide (CO). The confined space small area condition is preventing workers from a safe distance from potential hazards induced by faulty mechanical or electrical system. The chemical hazards can also be present due to the leakage of flammable liquid in poorly ventilated area. The situations also pose as potential hazards to the rescue personnel who attempted to save the workers during an accident. So the workers that are being assigned to work inside the confined space should be equipped with proper equipment and training on safety. Their safety should always be monitored while performing the job. Also, the area safety aspect such as minimum radius for entry and exit, ventilation system and work space as shown by Fig. 1 must be properly studied before performing their job [1]. The structure and technical specifications are designed based on the specific application to replace human for performing dangerous tasks, particularly mobile olfaction [2].

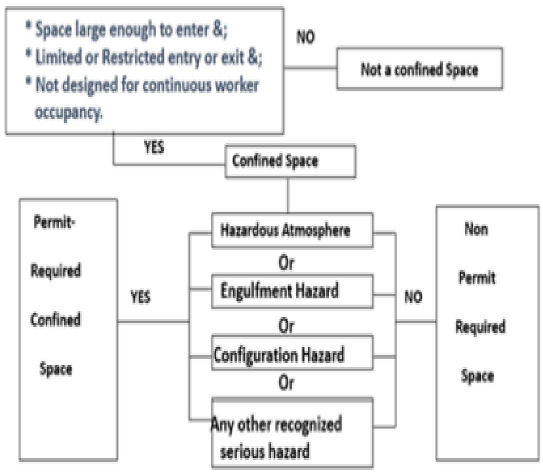

Figure 1: The confined space criteria [1]

II. LITERATURE REVIEW

In paper [1] we present a steering system for a space-saving four-wheel steering and four-wheel drive (4WS4WD) electric vehicle (EV) with higher maneuverability and flexibility. The proposed system consists of three main parts, namely, an improved two-front-wheel steering (2FWS) mechanism, an omnidirectional independent steering (OIS) mechanism integrated with steer-by-wire, and a control strategy for the space-saving steering system of an EV. The control strategy for the space-saving steering system of the EV is redefined for the integrated 2FWS and OIS, which can easily handle the EV for high-speed driving or high-maneuverability turning, such as ZRT and LP motion.

In paper [2], we apply the hierarchical model predictive tracking control for real robot and verify the travelling performance. We deal with the independent four-wheel driving/steering vehicle (IFWDS).. In our previous study, we achieved the improvement of tracking performance by optimal allocation of steering angle for CSM in simulation. In this study, we verify that we can obtain the same result in experiment.

In paper [3] a mobile robot structure is designed, modeled and simulated for confined space application. The mobile robot is designed to adopt four wheels skid-steering driving mechanism to allow immediate and sharp turning. The mathematical description of the robot is represented by static kinematic model.. Simulation is done to analyse the structure's stress and displacement. The analysis of the results indicates that the structure is suitable to be used for the confined space application.

In paper [4], the mechatronics design of a four wheel steered mobile robot is discussed in detail. Mechanical Low-level software architecture based on embedded pc-based control is designed that enables the robot to operate its eight independent actuators synchronously. Based on kinematics models, a fault tolerant wheel odometry is proposed to make the feedback robust to practical wheel odometry faults during the solution of forward kinematics.

Paper [5], Shape memory alloy (SMA) actuators are good candidates for actuators of mechatronic systems because they can minimize the size and weight of system. In this paper a solution for active locomotion of a robot is described. Inspired by inchworm locomotion, the authors present the design, development, simulation and testing of a small robot actuated by a pair of shape memory alloy springs.A simulation platform for observing the robot's behavior in addition to optimizing the robot parameters has been provided. Using the platform, a plan for activation of SMAs for forward motion or steering is extracted.Experimental results verified the robot ability to move straight or steer on a common plane.

[6] In this study, we propose the model predictive steering control for independent four-wheel driving and steering vehicles with coaxial steering mechanisms. The proposed method can consider physical constraints of actuators and achieve smooth and quick convergence of the steering to the target angle. We verify the efficiency of the proposed method by experiments using the vehicle which is equipped with an embedded CPU.

III. MOVEMENT TYPE AND WHEEL SELECTION

Mobile robot movement can either be using leg or wheel. Legged robot normally consists of two or four legs for movement [4]. While wheeled robot uses two, three of four circular frame or disk arranged to revolve on an axis of the body [3]. The structure must be stable during maneuver which is an issue for both movement type; legged and wheeled robot as it has small area of contact with ground [5]. So the selection of movement type is typically dependent on the robot application and targeted environment. The environment in confined space normally is limited and small so it is more suitable for wheel robot [1]. The wheel robot structure design is quite easy and popular because of its mobility, fast and energy efficient [5]. The robot structure ground clearance and tire pattern will determine the efficiency of power transfer from wheel to ground. The robot application also will decide numbers of wheels for weight distribution. Narrow wheels will be used for high speed with low power consumption while wide wheels will be selected for better grip [5]. Four wheel configurations are selected for the structure design because of the easy control, good mobility and well balance that is suitable for the confined space harsh environment. The configuration is more stable because usually the wheel is attached at each corner of either rectangular or square shaped robot's structure. The wheels are placed on the right, left, front and back side of the robot's structure that will increase the development efficiency [5]. The wheel robot is stable and suitable for carrying heavy load because of the structure's even wheel will improve contacts with ground. The centrifugal forces will ease the risk of robot become unstable and rolling over while turning [5]. The configuration also provides an optimal surface area for integrating robot components such as batteries, motors and controller boards.

IV. STEERING SELECTION

Mobile robot driving mechanism can be classified into three types; skid steering, ackerman and axle articulated. Skid steering driving mechanism which uses differential drive concept is suitable for either tracks or wheels robot [7]. The skid steering driving mechanism provides higher visibility and normally easier to control by using joy-sticks or remote control. But ackerman steering need to add more mechanical structure to control the movement of robot. For operation of mobile robot inside confined space, wheelskid steering driving mechanism is selected because of its suitability with four wheel configuration. Two wheels on each side that drive in the same direction are used for driving and steering the robot [8]. The mechanism is based on controlling the relative velocities of left and right side wheels, which is similar to differential drive. The mechanism is simple and quite robust with good traction make it suitable for rough surface inside the confined space. The robot can perform various postural and unique motions with good stability and versatility [6]. The drive mechanism will control driving motion, obstacle avoidance or rough surface movement. It provides better maneuverability with zero-radius turning and quite efficient for straight-line movement [8].

V. MATERIAL SELECTION

The type of material used for structure will determine the durability and reliability of the robot. Costs, performance, safety, risk, aesthetics and environmental impact are the criteria to consider while selecting material for the robot's structure. The material selections are also influenced by the structure design and the environment [6]. Most of the robot structures in the literature were made of steel, aluminum or plastic [7]. Plastic is normally used in remote controlled robots which usually complete with drive system. However, plastic is unsuitable for the robot structure material because its lack of durability and strength for extreme conditions in confined space. Typically aluminum or steel are used as the robot structure material because of its cost and strength advantage. By considering the young's modulus for cost and strength combination in Fig. 3, mild steel is selected for the robot structure material. The selected material is also suitable for the robot rectangular structure. Hollow rectangular mild steel bars are used for robot's structure to enhance the body strength and increase its carrying load capacity.

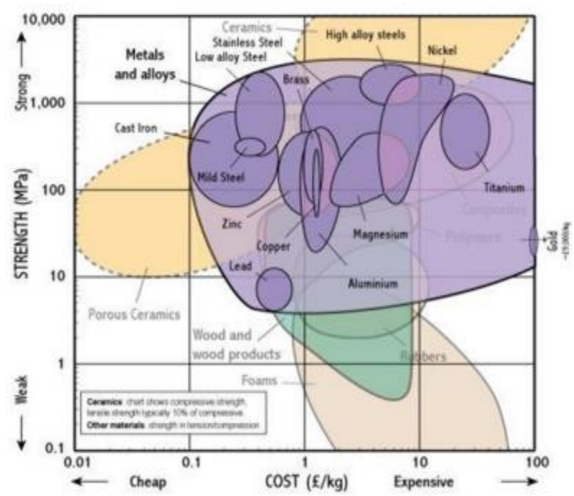

Figure 3. Robot strength and cost correlation [11]

VI. KINEMATICS

A. *Model of independent four-wheel driving/steering vehicle*

X − Y is the inertia coordinate system; x − y is the body coordinate system fixed to the vehicle. We define that the position of center of gravity (CoG) is (X_g, Y_g); the attitude angle is θ; on the inertia coordinate system.

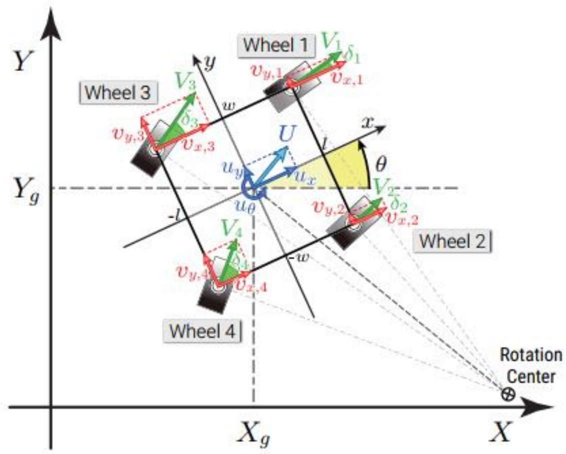

Fig. 2: The kinematic model of IFWDS[6].

The translational and angular velocities are u_x, u_y, u_θ. Then, the state space equation of this robot is represented by

$$\frac{d}{dt}\begin{bmatrix} X_g \\ Y_g \\ \theta \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} u_x \\ u_y \\ u_\theta \end{bmatrix}. \quad (1)$$

The reference wheel velocity Vi and reference steering angle $\delta_{i,r}$ are calculated from

$$\delta_{i,\mathrm{r}} = \tan^{-1}\left(\frac{v_{\mathrm{y},i}}{v_{\mathrm{x},i}}\right), \quad (2)$$

$$V_i = v_{\mathrm{x},i}\cos\delta_i + v_{\mathrm{y},i}\sin\delta_i, \quad (3)$$

where v_x,i, v_y,i are the x and y elements of V_i.

VII. CONTROL METHOD

A. Model predictive tracking control

Model predictive tracking control is a kind of tracking controller which predicts future motion until finite time and to compute the optimum input. The state space equation of this system is represented by

$$\dot{\boldsymbol{x}}_{\mathbf{t}} = f(\boldsymbol{x}_{\mathbf{t}}, \boldsymbol{u}_{\mathbf{t}}), \quad (7)$$

where

$$\boldsymbol{x}_{\mathbf{t}} = \left[X_{\mathrm{g}}, Y_{\mathrm{g}}, \theta, \boldsymbol{V}^T, \boldsymbol{\delta}^{\mathrm{T}}\right]^{\mathrm{T}}, \quad (8)$$

$$\boldsymbol{u}_{\mathbf{t}} = \left[\boldsymbol{a}^{\mathrm{T}}, \boldsymbol{\omega}^{\mathrm{T}}\right]^{\mathrm{T}}, \quad (9)$$

$$f(\boldsymbol{x}_{\mathbf{t}}, \boldsymbol{u}_{\mathbf{t}}) = \begin{bmatrix} \left\{(\bar{V_1})\cos\theta - (\bar{V_2})\sin\theta\right\}/2 \\ \left\{\bar{V_1}\sin\theta + \bar{V_2}\cos\theta\right\}/2 \\ \{\bar{V_3}/w + \bar{V_4}/l\}/8 \\ \boldsymbol{a} \\ \boldsymbol{\omega} \end{bmatrix}, \quad (10)$$

with

$$\bar{V_1} = V_1\cos\delta_1 + V_2\cos\delta_2, \quad (11)$$

$$\bar{V_2} = V_1\sin\delta_1 + V_3\sin\delta_3, \quad (12)$$

$$\bar{V_3} = V_2\cos\delta_2 - V_1\cos\delta_1 + V_4\cos\delta_4 - V_3\cos\delta_3, \quad (13)$$

$$\bar{V_4} = V_1\sin\delta_1 - V_3\sin\delta_3 + V_2\sin\delta_2 - V_4\sin\delta_4, \quad (14)$$

where V= [V_1, V_2, V_3, V_4] T and δ= [δ_1, δ_2, δ_3, δ_4] ^{T} are the wheel velocity of each wheel and the reference steering angle of each wheel, respectively. a and ω are the each wheel acceleration a_i = V_i and steering angular velocity ω_i = δ_i, respectively. When the movable range of each wheel is confined to $\bar{\delta}$, unequally constraints with respect to movable range of each wheel are represented by

$$g_i(\boldsymbol{x}_{\mathbf{t}}) = \delta_i^2 - \bar{\delta}^2 \leq 0. \qquad (i = 1, 2, 3, 4) \quad (15)$$

We define the reference state vector as $\boldsymbol{x}_{\mathbf{t,r}} = [X_{\mathrm{g,r}}, Y_{\mathrm{g,r}}, \theta_{\mathrm{r}}, V_{1,\mathrm{r}}, V_{2,\mathrm{r}}, V_{3,\mathrm{r}}, V_{4,\mathrm{r}}, \delta_{1,\mathrm{r,U}}, \delta_{2,\mathrm{r,U}}, \delta_{3,\mathrm{r,U}}, \delta_{4,\mathrm{r,U}}]^{\mathrm{T}}$. The index function is represented by

$$J = \phi_{\mathrm{t}}(\boldsymbol{x}_{\mathbf{t}}(t + T_{\mathrm{h,U}}), t + T_{\mathrm{h,U}}) + \int_t^{t+T_{\mathrm{h,U}}(t)} L_{\mathrm{t}}(\boldsymbol{x}_{\mathbf{t}}(\tau), \boldsymbol{u}_{\mathbf{t}}(\tau), t)d\tau, \quad (16)$$

where T_h ,u (t) is a prediction length for model predictive tracking control. φ_t and L_t are a terminal cost and a stage cost, respectively. They are represented by

$$\phi_t(\boldsymbol{x}_t(t), t) = \frac{1}{2}(\boldsymbol{x}_t(t) - \boldsymbol{x}_r(t))^T \boldsymbol{S}_f(\boldsymbol{x}_t(t) - \boldsymbol{x}_r(t)), \quad (17)$$

$$\begin{aligned} L_t(\boldsymbol{x}_t(t), \boldsymbol{u}_t(t), t) &= \frac{1}{2}(\boldsymbol{x}_t(t) - \boldsymbol{x}_r(t))^T \boldsymbol{Q}(\boldsymbol{x}_t(t) - \boldsymbol{x}_r(t)) \\ &+ \frac{1}{2}\boldsymbol{u}_t(t)^T \boldsymbol{R}\boldsymbol{u}_t(t) \\ &+ \frac{1}{2}C(\boldsymbol{x}_t(t))^T \boldsymbol{W} C(\boldsymbol{x}_t(t)) \\ &+ \frac{1}{\rho}\sum_{i=1}^{4}(-\log(-g_i(\boldsymbol{x}_t(t)))), \quad (18) \end{aligned}$$

where S_f, Q, R, W are the positive definite weight matrices and ρ is a weight constant.

B. *Model predictive steering control*

we proposed a steering control method considering the features of each joint using model predictive control [8]. The index function of this steering control is represented by

$$J = \phi_s(\boldsymbol{x}_{s,i}(t+T_{h,L}), t+T_{h,L}) + \int_t^{t+T_{h,L}} L_s(\boldsymbol{x}_{s,i}(\tau), \boldsymbol{u}_{s,i}(\tau), \tau)d\tau, \quad (19)$$

where $T_{h,L}$ is the predictive length in model predictive steering control. φ_s and Ls denote the terminal cost and stage cost, respectively. They are represented by

$$\phi_s(\boldsymbol{x}_{s,i}(t), t) = \frac{1}{2}S_e(\delta_{i,1}(t) + \delta_{i,2}(t) - \delta_{i,r,L}(t))^2 + \frac{1}{2}S_1\delta_{i,2}^2(t), \quad (20)$$

$$\begin{aligned} L_s(\boldsymbol{x}_{s,i}(t), \boldsymbol{u}_{s,i}(t), t) &= \frac{1}{2}Q_e(\delta_{i,1}(t) + \delta_{i,2}(t) - \delta_{i,r,L}(t))^2 \\ &+ \frac{1}{2}Q_1\delta_{i,2}^2(t) \\ &+ \frac{1}{2}R_0\omega_{i,1}^2(t) + \frac{1}{2}R_1\omega_{i,2}^2(t), \quad (21) \end{aligned}$$

where Qe, Q1 and R0, R1 are the weight constant for evaluation of steering angle and steering angular velocity in stage cost, respectively. Se, S1 are the weight constant for evaluation of steering angle in terminal cost. The first term evaluates the error between the steering angle of CSM and the its reference. The second term evaluates the steering angle of joint No.2 to suppress the magnitude and return to the neutral direction. We set the weight of first term larger than it of second term. The third and fourth terms in stage cost evaluate the angular velocity to suppress the rapid change of steering.

VIII. CONCLUSION

The controlling behavior of a vehicle is influenced by the performance of its steering system. The steering system consists of steering wheel, steering column, rack and pinion, steering gearbox, and a linkage system. The vehicle is controlled by the behavior of the steering gear with the spring loaded rack and pinion. In standard 2 Wheel Steering System, the rear set of wheels are always directed forward and do not play an active role in controlling the steering. While in 4 Wheel Steering System, the rear wheels do play an active role for steering, which can be guided at high as well as low speeds. Production cars are designed to under steer and rarely do they over steer. Production cars are designed to under steer and rarely do they over steer. If a car could automatically compensate for an under steer/over steer problem, the driver would enjoy nearly neutral steering under varying operating conditions. Four-wheel steering is a serious effort on the part of automotive design engineers to provide nearneutral steering. Also in situations like low speed cornering, vehicle parking and driving in city conditions with heavy traffic in tight spaces, driving would be very difficult due to vehicle's larger wheelbase and track width. Hence there is a requirement of a mechanism which result in less turning radius and it can be achieved by implementing four wheel steering mechanism instead of regular two wheel steering.

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