2018 1st Workshop for Zhao Lab of Safe AI Learning and Engineering Research (SAILER)

Chengyuan Zhang (intern)

Undergraduate

enzozcy@cqu.edu.cn

Mechanical Engineering, SAILER Lab
Carnegie Mellon University

Automotive Engineering, SKLMT Lab
Chongqing University

August 25, 2018 CMU

Part I

Chaotic Behavior of Magnetorheological Suspension

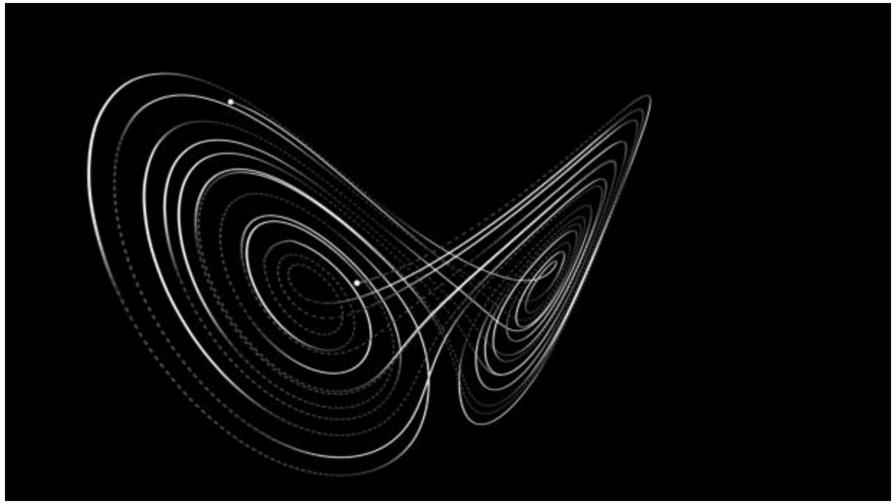
Part II

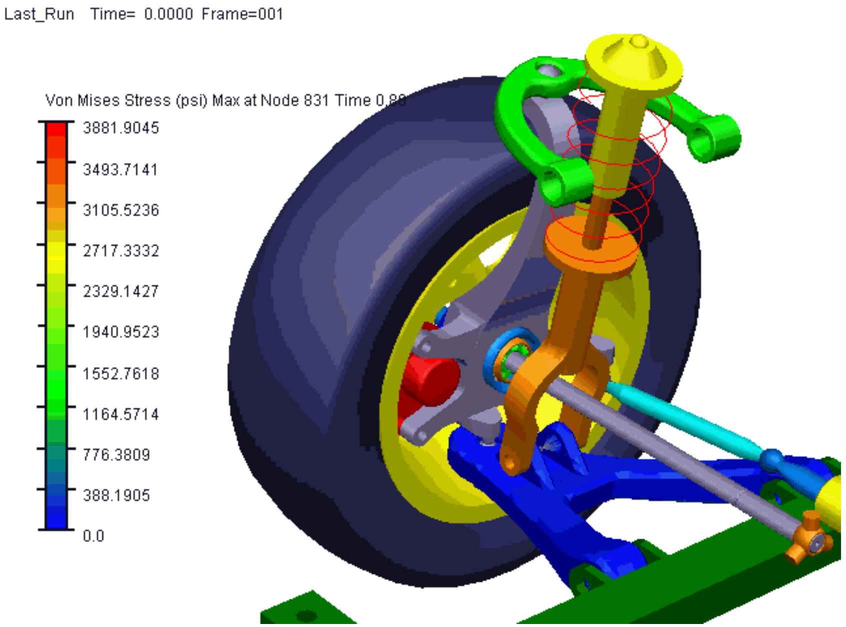
Design of a Novel Cam-Linkage Mechanism

[Part I] Chengyuan Zhang, Jian Xiao, "Chaotic Behavior and Feedback Control of Magnetorheological Suspension System with Fractional-Order Derivative," *Journal of Computational and Nonlinear Dynamics*, 2018.
[Part II] Chengyuan Zhang, Xianxiong Ning, Xiaomin Zhang, Hongyun Ye, "Design and Kinematic Analysis of a Novel Cam-Linkage Double Parallelogram Mechanism with Filleted Rectangular Trajectory," *Journal of Mechanisms and Robotics*, 2018. (Under Review)

Part I

Chaotic Behavior of Magnetorheological Suspension

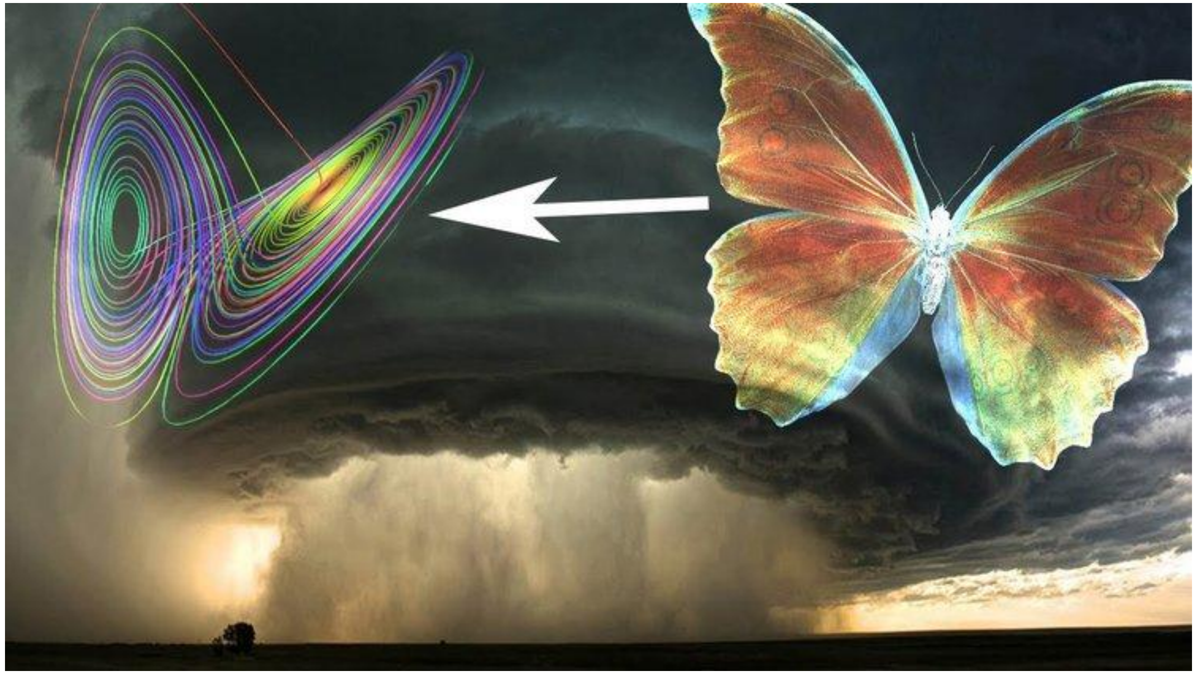




[1]

[1] Picture from: https://www.reddit.com/r/gifs/comments/2vs0p7/suspension_control_arm_stress/

1. Introduction



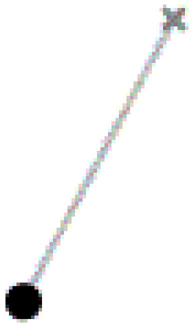
"… a butterfly flapping its wings in ANYWHERE can cause a hurricane in Texas."

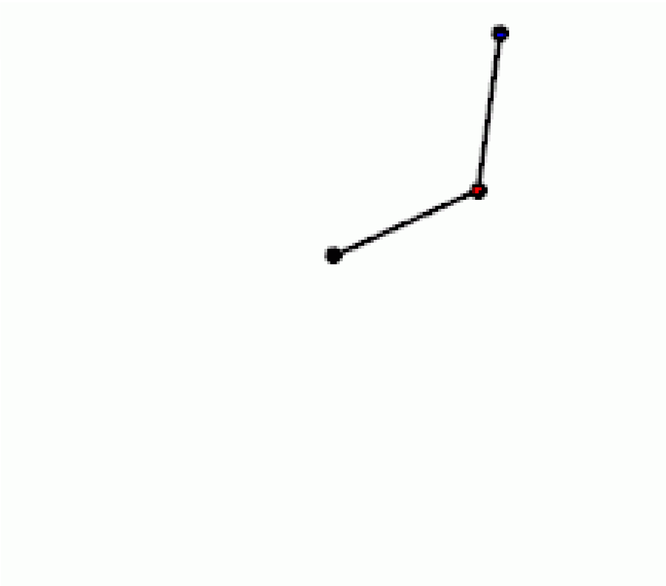
"Chaos: When the present determines the future, but the approximate present does not approximately determine the future." [2]

—— Edward Lorenz

[2] Danforth, Christopher M. (April 2013). "Chaos in an Atmosphere Hanging on a Wall". Mathematics of Planet Earth 2013. Retrieved 12 June 2018.

1. Introduction





Single-rod pendulum

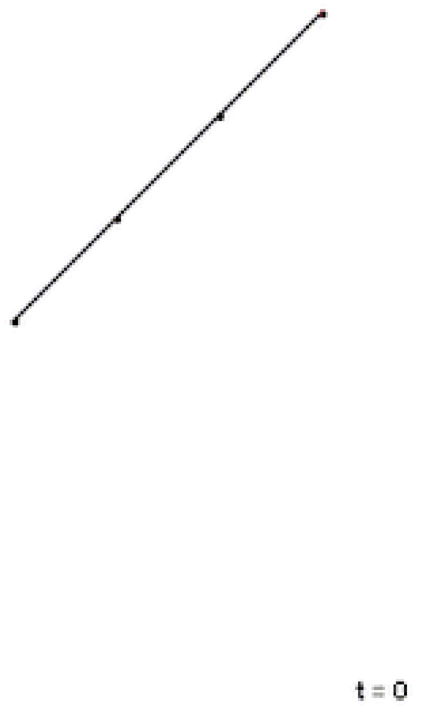
periodic

Double-rod pendulum

?

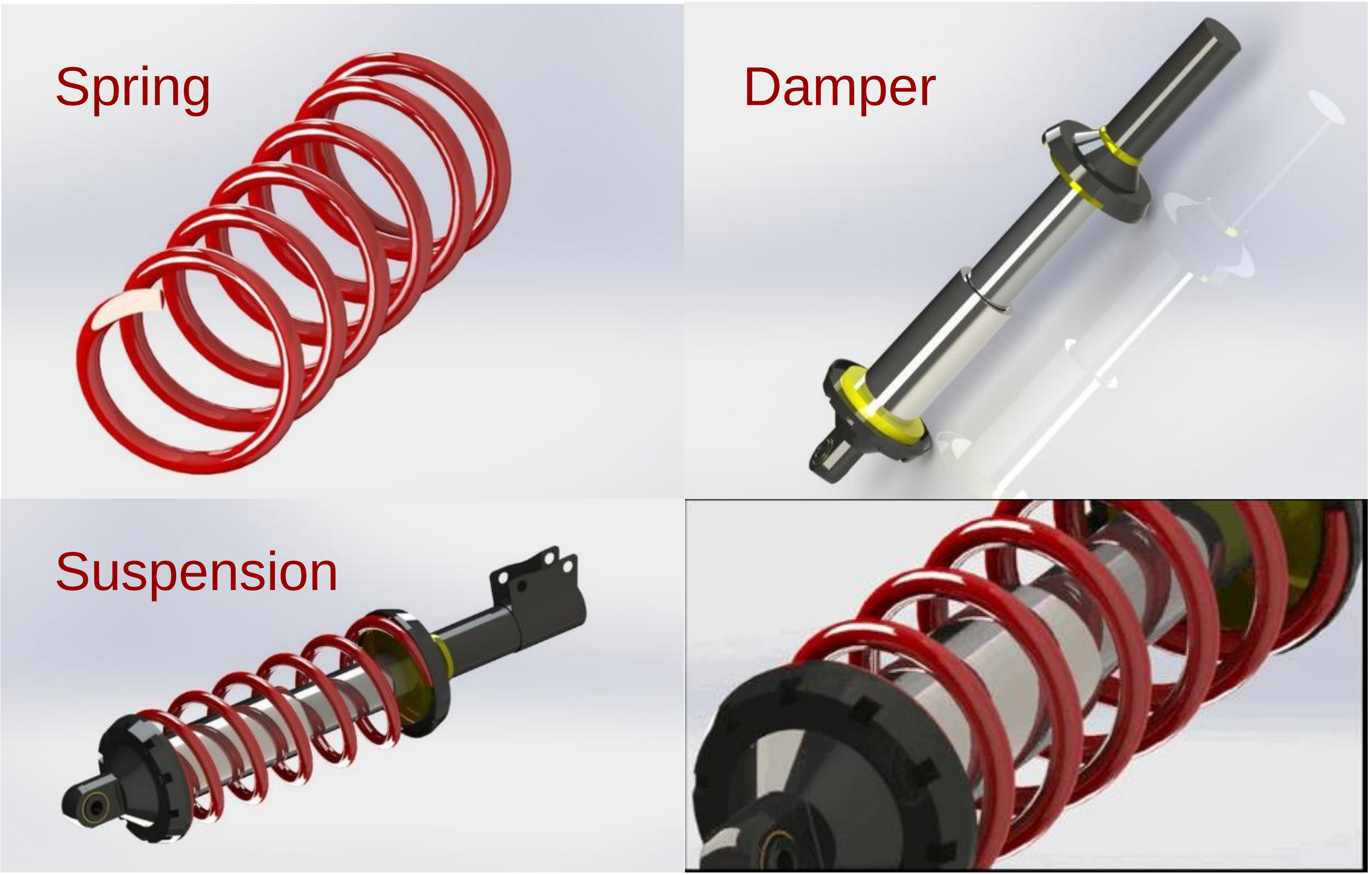
1. Introduction

Chaos theory is a branch of mathematics focusing on the behavior of **dynamical systems** that are highly sensitive to **initial conditions**. [3]



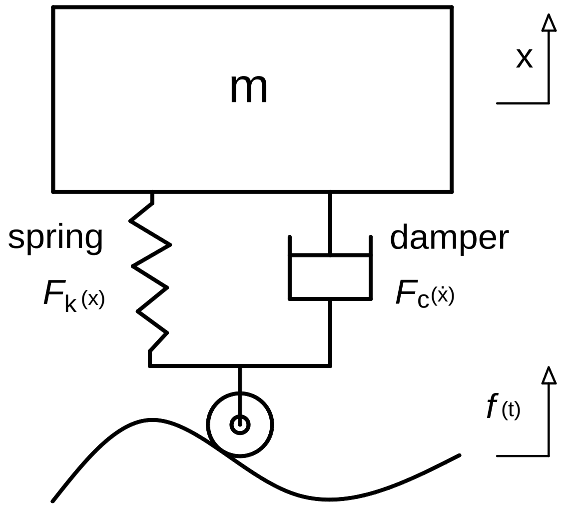
[3] https://en.wikipedia.org/wiki/Chaos_theory

2. 1/4-Car Suspension



[4] Pictures from https://grabcad.com/library/car-suspension

2. 1/4-Car Suspension



(a) A quarter-car suspension system

(b) Suspension Dynamic

$$\boxed{m\ddot{x} = F}$$

$$\downarrow$$

$$\boxed{m\ddot{x} + c\dot{x} + kx = F_{(t)}}$$

$$\downarrow$$

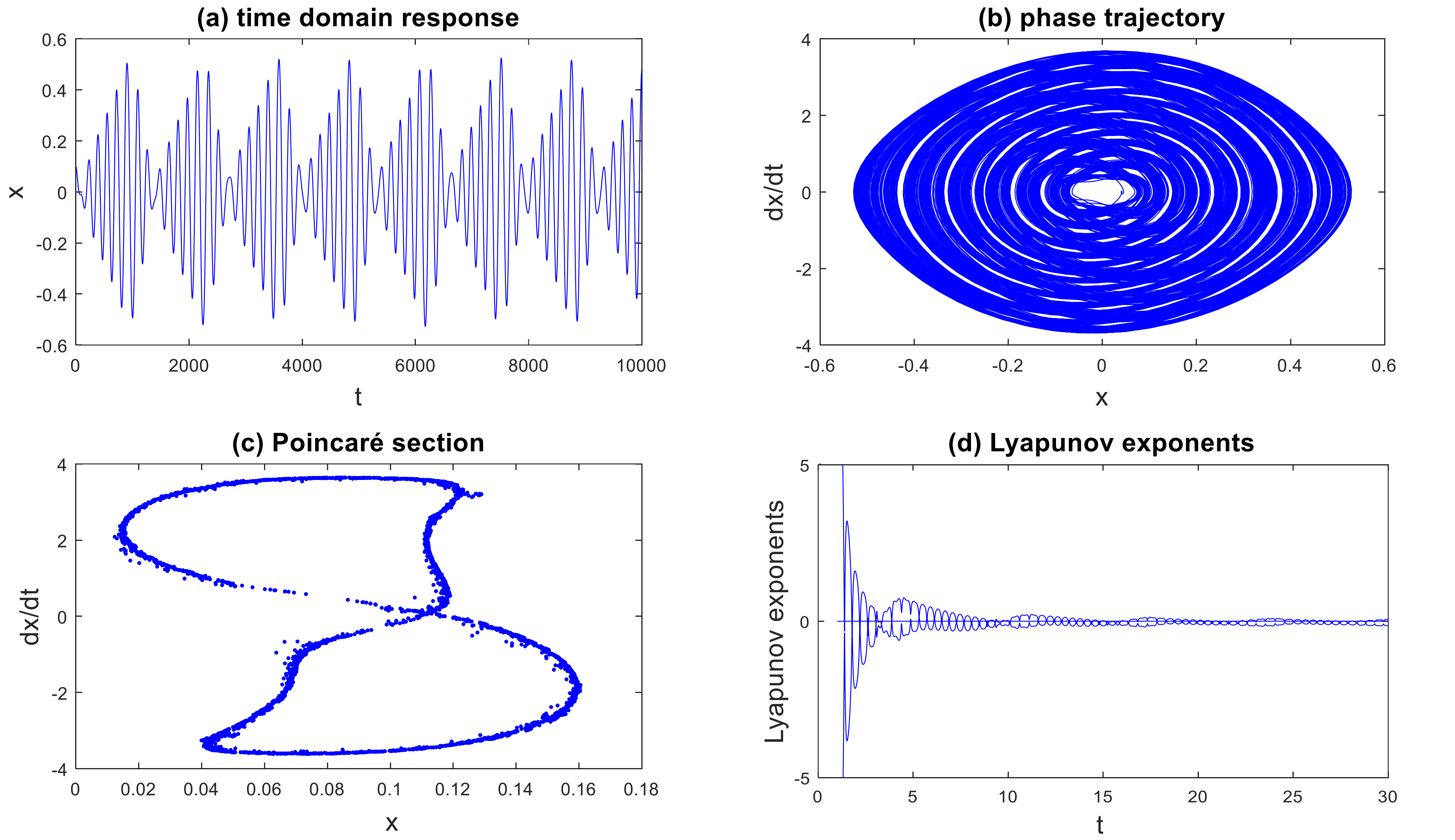
$$\boxed{m\ddot{x} + k_1(x - f_{(t)}) + k_2(x - f_{(t)})^3 + c_1(\dot{x} - \dot{f}_{(t)}) + c_2(\dot{x} - \dot{f}_{(t)})^3 = 0}$$ [5]

$$y = x - f_{(t)} \quad \downarrow \quad f_{(t)} = A_0 \sin(\omega t)$$

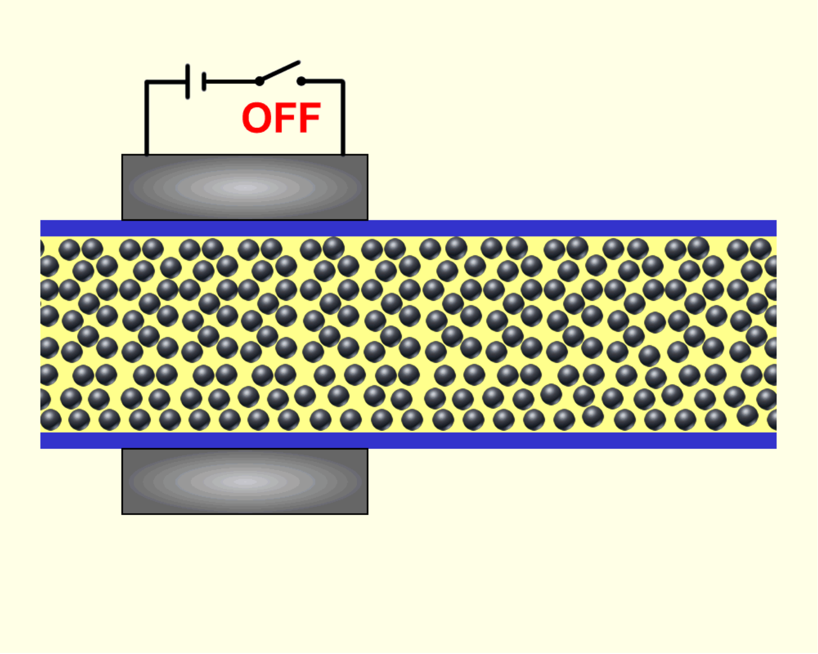
$$\boxed{\begin{cases} \dot{y} = z \\ \dot{z} = A_0\omega^2 \sin(\omega t) - Ay - By^3 - Cz - Dz^3 \end{cases}}$$

[5] Litak, G., & Borowiec, M. (2006). Nonlinear vibration of a quarter-car model excited by the road surface profile. Communications in Nonlinear Science & Numerical Simulation, 13(7), 1373-1383.

2. 1/4-Car Suspension



3. Fractional Derivatives



Magnetorheological Fluid

MR suspension V.S. Standard suspension

3. Fractional Derivatives

------- MR Suspension -------

Mainardi, F. 2010

“The theory of viscoelasticity is widely used in fractional calculus.”

Spanos, P. D. 2010

“…the experimental data have a good fit as the viscoelastic damping materials is described by fractional calculus.”

Kai, D. 2002

“The numerical integration is carried out based on the predictor–corrector method.”

Sreekar Reddy, M. B. S. 2017

“…demands on the comfort and stability…”

Liem, D. T. 2015

“The integer differential equation can neither accurately depict the dynamic behavior nor reveal the actual physical characteristics.”

Ma, S. 2014

“…by applying the fractional order differential operator we can be described the actual dynamic characteristics of chaotic systems more accurately.”

3. Fractional Derivatives

The general calculus operator [6] :

$$ {}_aD_t^q x(t) = \begin{cases} \dfrac{d^q}{dt^q} x(t), & \mathrm{Re}(q) > 0 \\ x^{(n)}(t), & q = n \\ \displaystyle\int_a^t x(t)(d\tau)^{-q}, & \mathrm{Re}(q) < 0 \end{cases} $$

The Riemann-Liouville derivative [7] :

$$ {}_\alpha D_t^q x(t) = \frac{1}{\Gamma(n-q)} \frac{d^n}{dt^n} \int_a^t \frac{x(\tau)}{(t-\tau)^{q-n+1}} d\tau \quad (n-1 \le q < n) $$

$$ \begin{cases} \dot{y} = z \\ \dot{z} = A_0\omega^2 \sin(\omega t) - Ay - By^3 - Cz - Dz^3 \end{cases} $$

Fractional order

$$ \begin{cases} \dfrac{\mathrm{d}^{q_1} y}{\mathrm{d}t^{q_1}} = z \\ \dfrac{\mathrm{d}^{q_2} z}{\mathrm{d}t^{q_2}} = A_0\omega^2 \sin(\omega t) - Ay - By^3 - Cz - Dz^3 \end{cases} $$

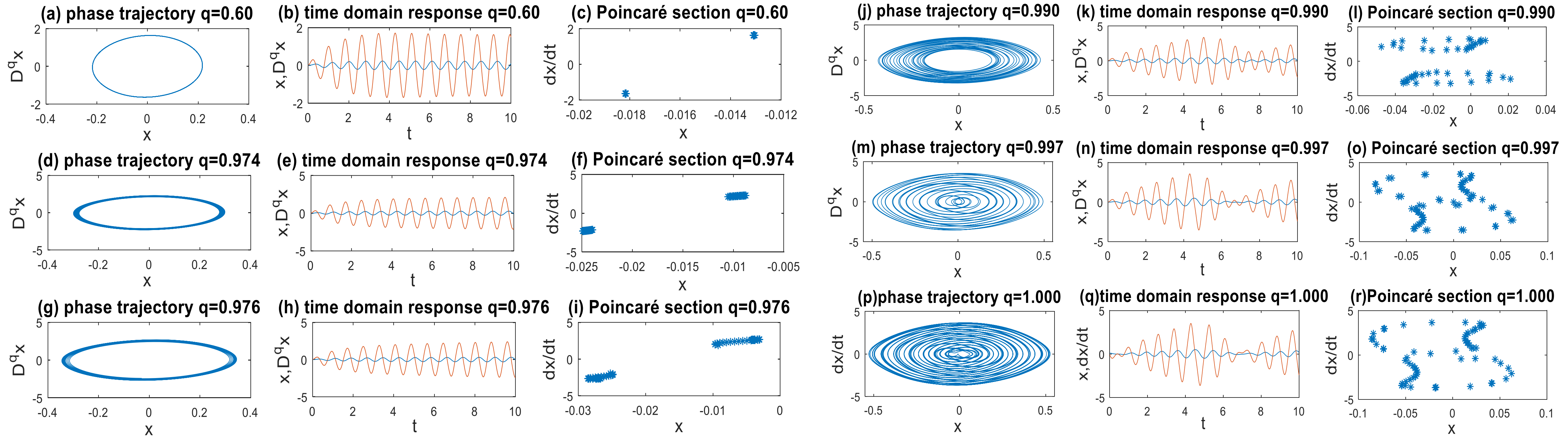
Discretized

$$ \begin{cases} y_{n+1} = y_0 + \dfrac{h^{q_1}}{\Gamma(q_1+2)} (z_{n+1}^* + \displaystyle\sum_{j=0}^{n} \alpha_{1,j,n+1} z_j) \\ z_{n+1} = z_0 + \dfrac{h^{q_2}}{\Gamma(q_2+2)} \{A_0\omega^2 \sin[\omega(n+1)h] - Ay_{n+1}^* - B{y_{n+1}^*}^3 - Cz_{n+1}^* - D{z_{n+1}^*}^3 \\ \qquad + \displaystyle\sum_{j=0}^{n} \alpha_{2,j,n+1} [A_0\omega^2 \sin(\omega jh) - Ay_j - By_j^3 - Cz_j - Dz_j^3]\} \end{cases} $$

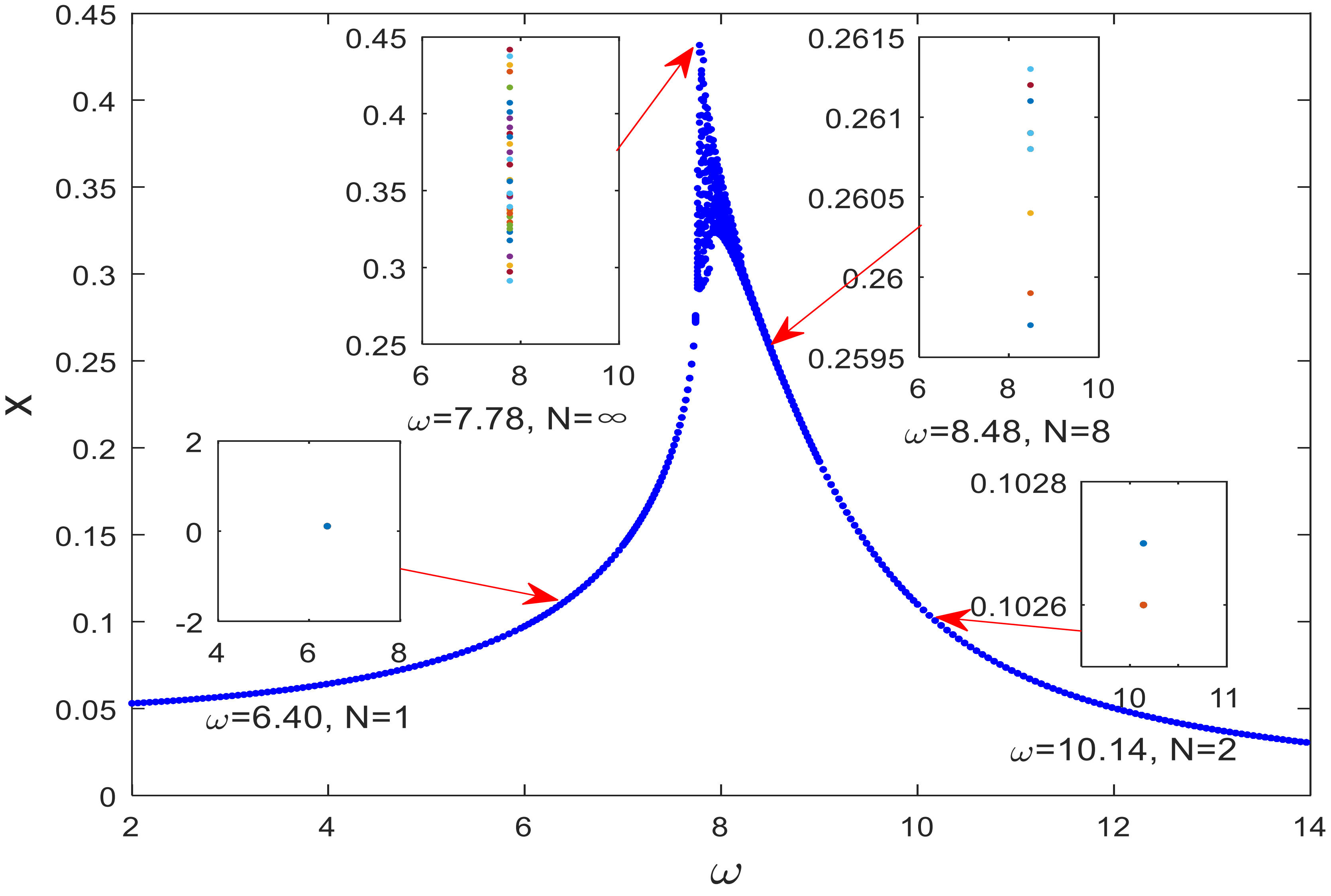
[6] Petráš, I. (2009). Chaos in the fractional-order Volta’s system: modeling and simulation. Nonlinear Dynamics, 57(1-2), 157-170.

[7] Scherer, R., Kalla, S. L., Tang, Y., & Huang, J. (2011). The Grünwald–Letnikov method for fractional differential equations. Computers & Mathematics with Applications, 62(3), 902-917.

3. Fractional Derivatives



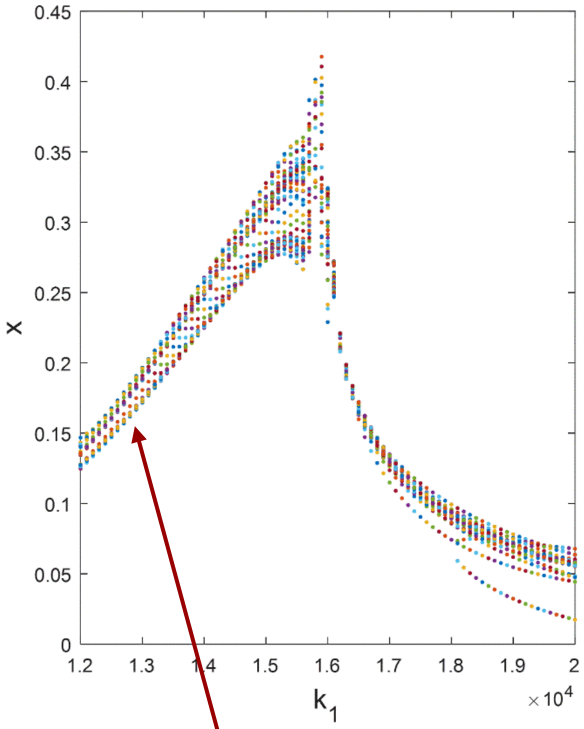
4. Chaos Control

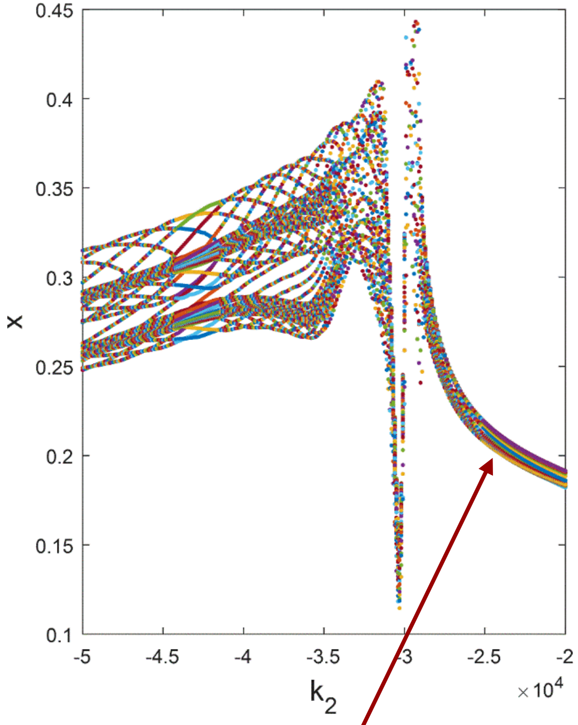


4. Chaos Control

In this section, we take q=0.980, ω=7.78 rad/s.

x-k Bifurcation

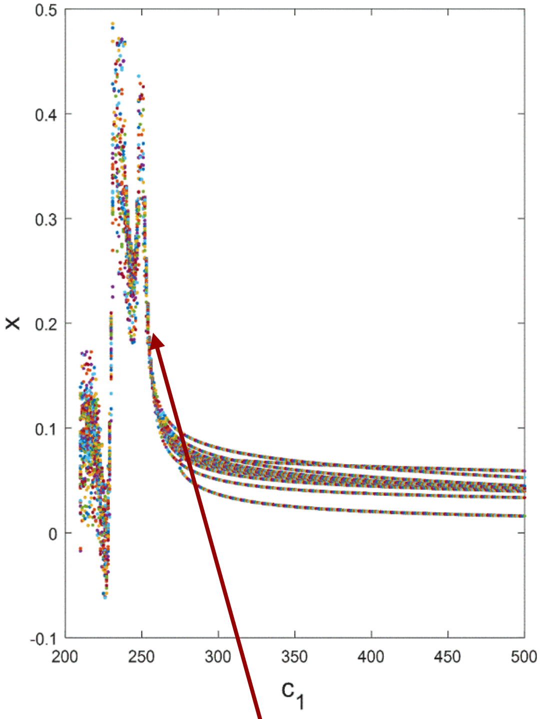


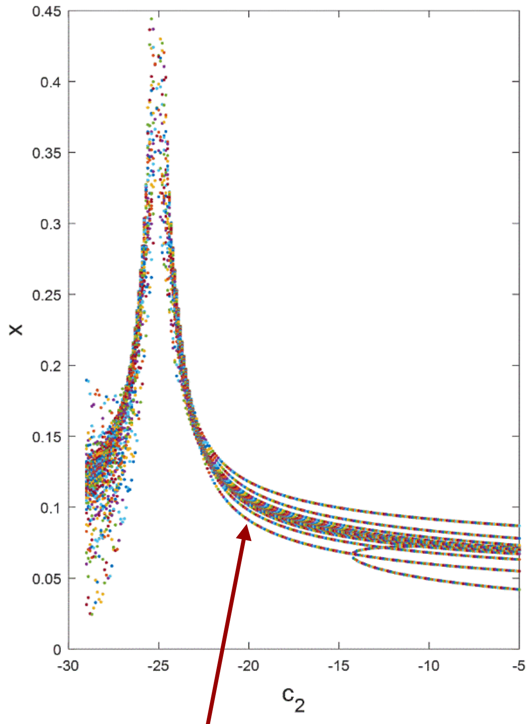


$k_1 = 13000$

$k_2 = -25000$

x-c Bifurcation





$c_1 = 260$

$c_2 = -20$

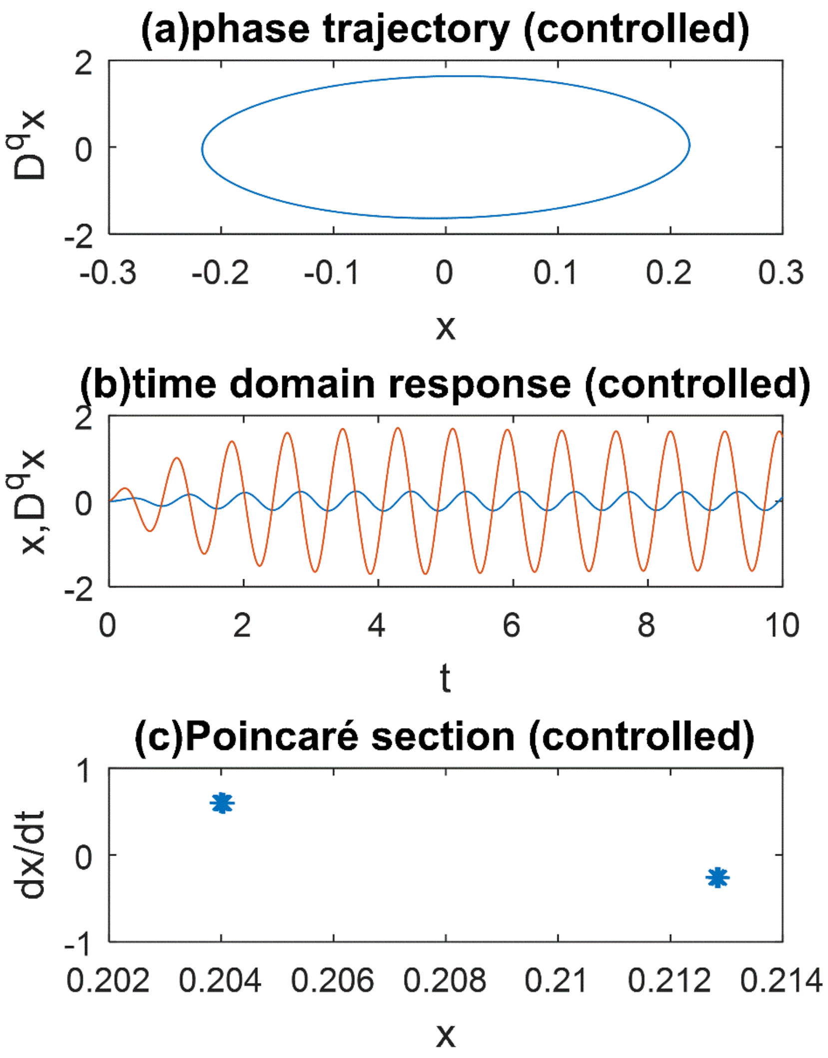
4. Chaos Control

$$k_1 = 13000$$

$$k_2 = -25000$$

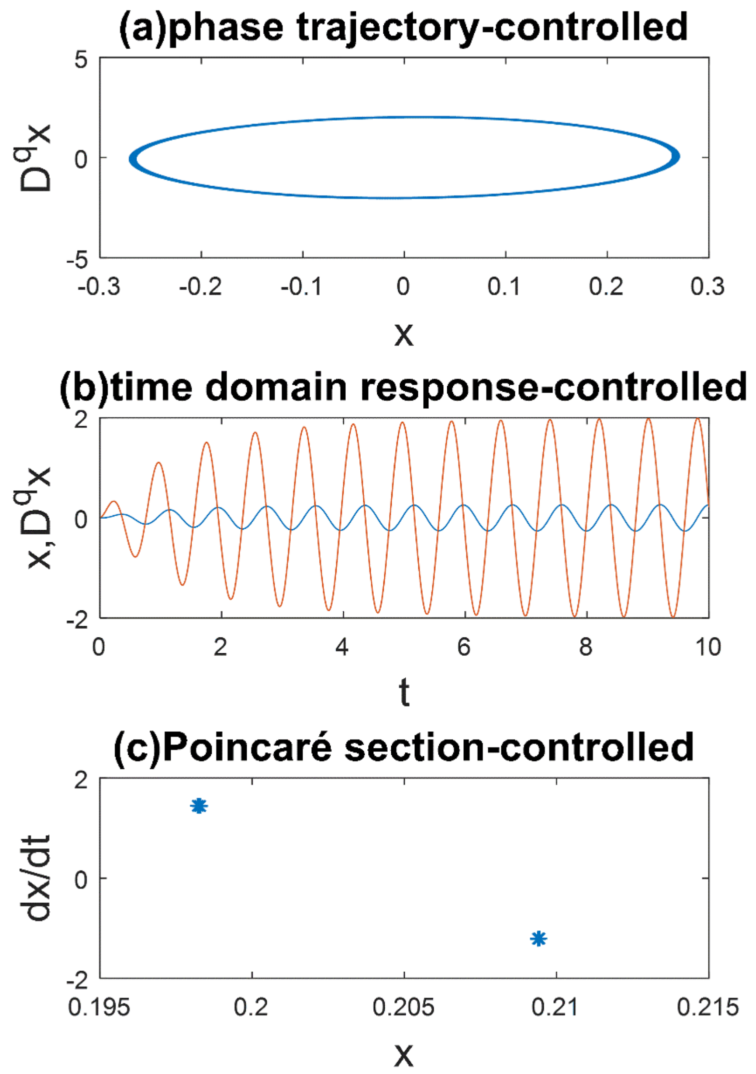
$$c_1 = 260$$

$$c_2 = -20$$



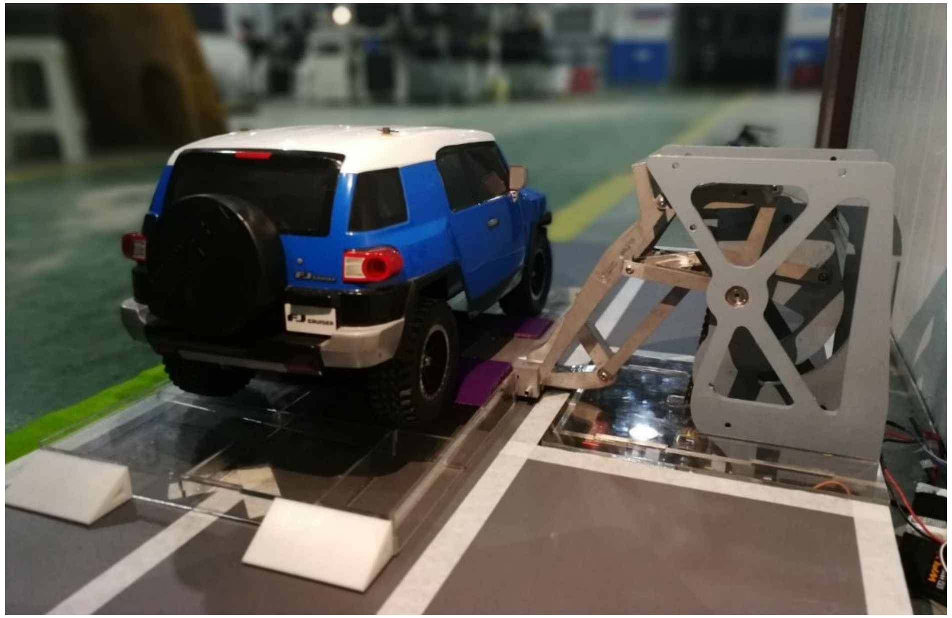
4. Chaos Control

$$\begin{cases} \dfrac{d^{q_1} y}{dt^{q_1}} = z - K_1 y \\ \dfrac{d^{q_2} z}{dt^{q_2}} = A_0\omega^2 \sin(\omega t) - Ay - By^3 - Cz - Dz^3 - K_2 z \end{cases}$$

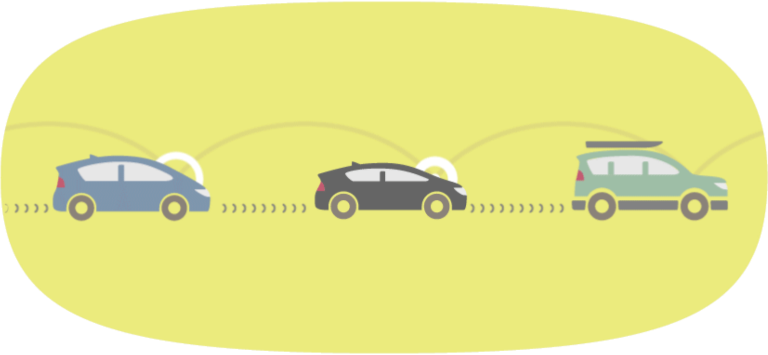


Part II

Design of a Novel Cam-Linkage Mechanism



1. Introduction



Connected vehicles

Car sharing

Automated vehicles

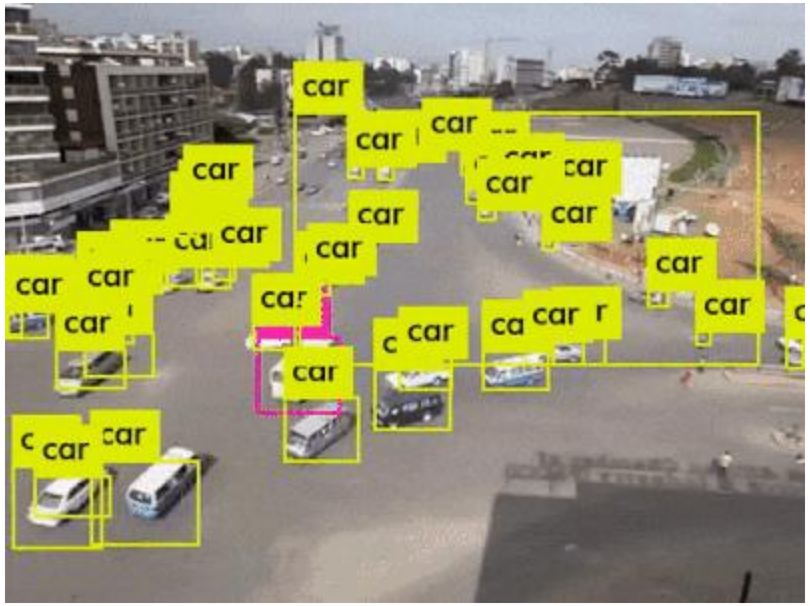
Ultra-compact electric vehicles

1. Introduction

Traffic jam

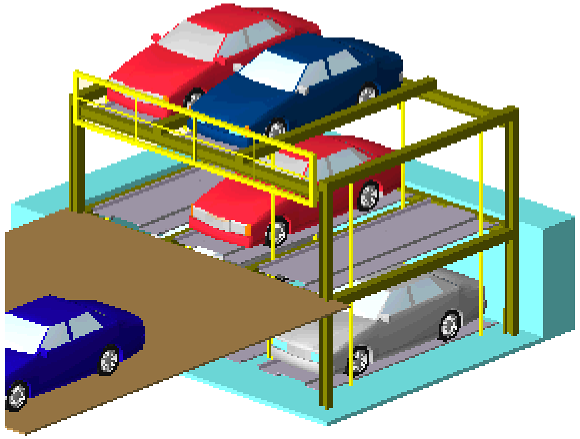
Problems

Parking difficulty



1. Introduction

How mechanisms help with parking difficulty:

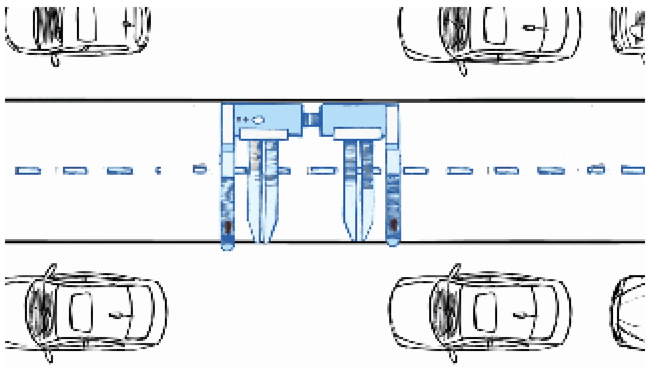


Parking management

(parking garage)

Smart parking device

(height limit)



Automated Parking

(convenience)

1. Introduction

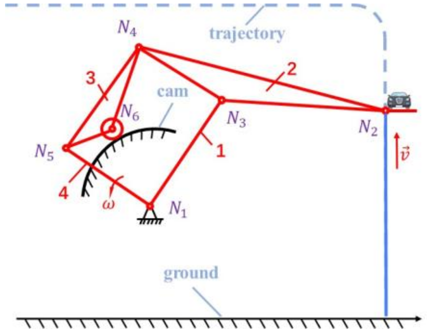
How mechanisms help with parking difficulty:

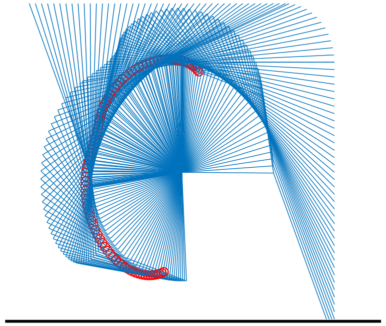
Standard parking device

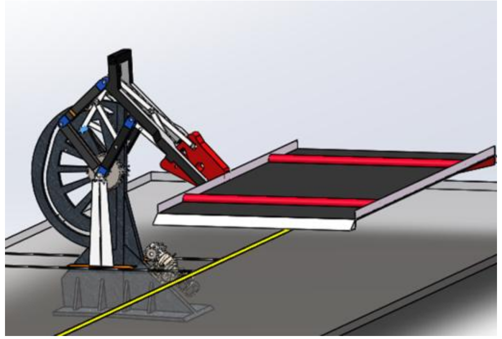
1. Introduction

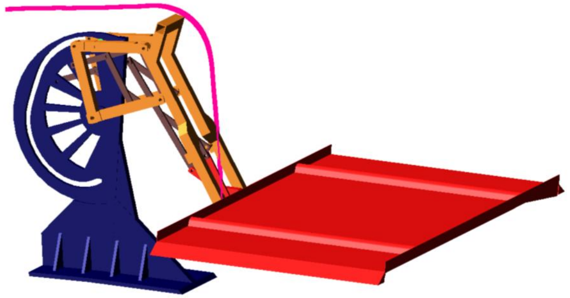
- Parallel parking spot;
- Double stack parking;
- Non-avoidance;

2. Design Method









Mathematical Model

Matlab Trajectory Simulation

SolidWorks CAD model

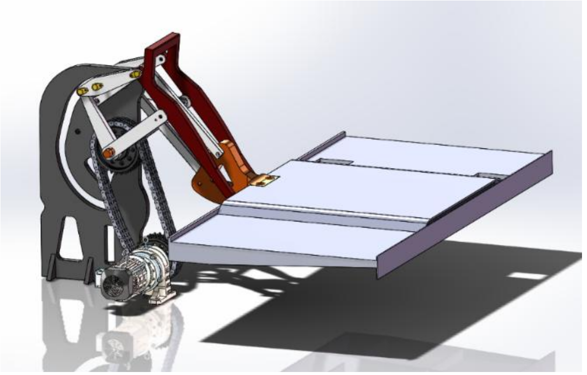
Adams Motion Simulation

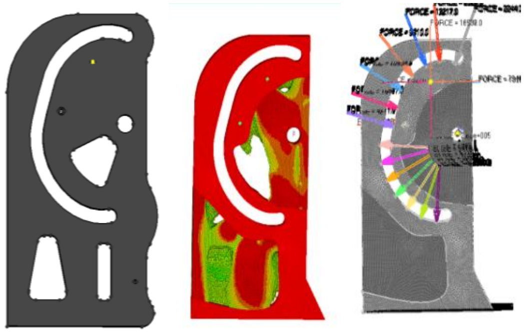
Prototype

Parts Processing

SolidWorks CAD Assembly

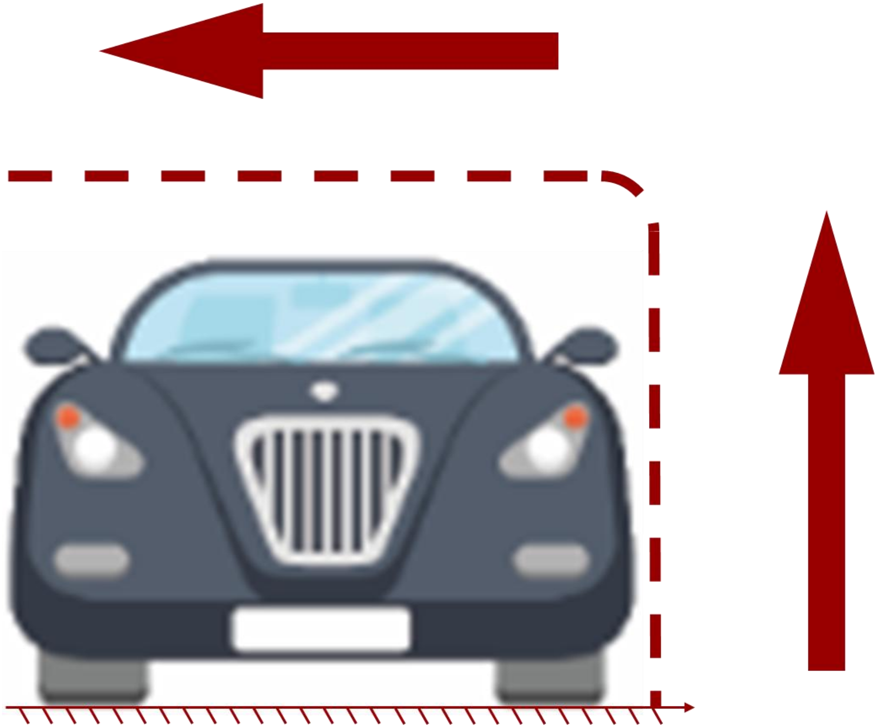
FAE Structure Optimization



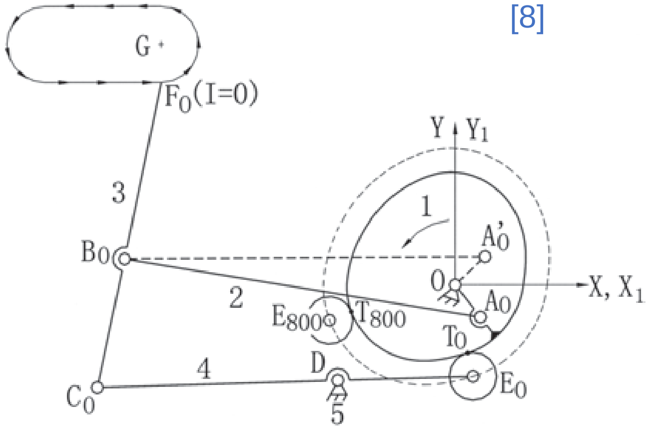


2. Design Method

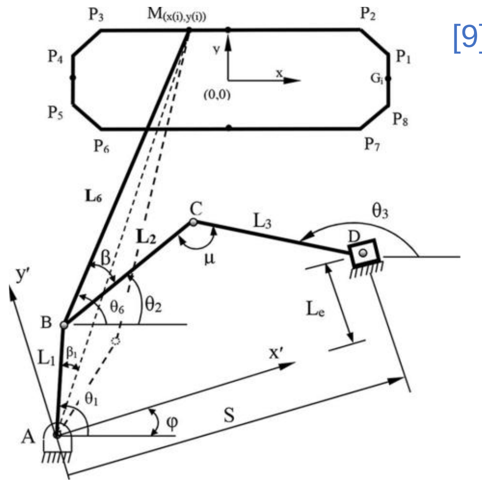
- **Non-avoidance:**
Rectangular trajectory

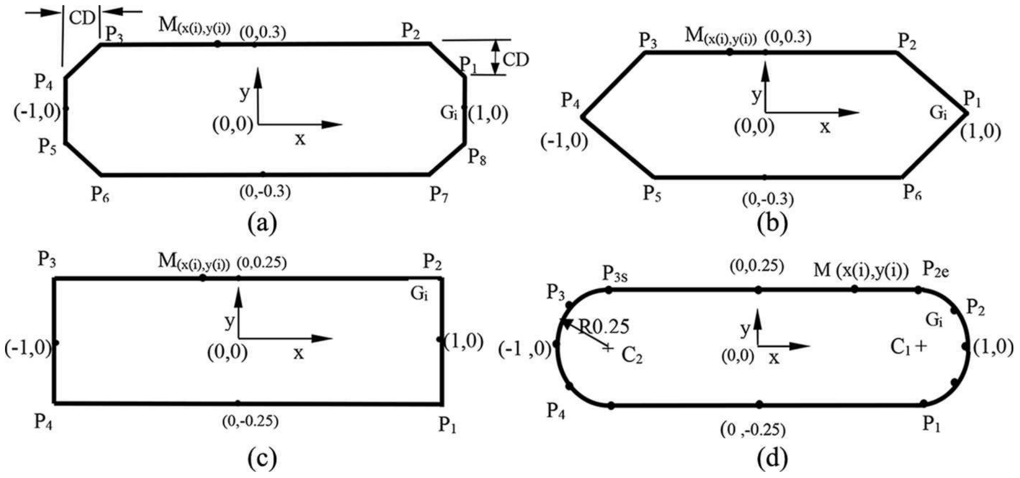


[8]



[9]





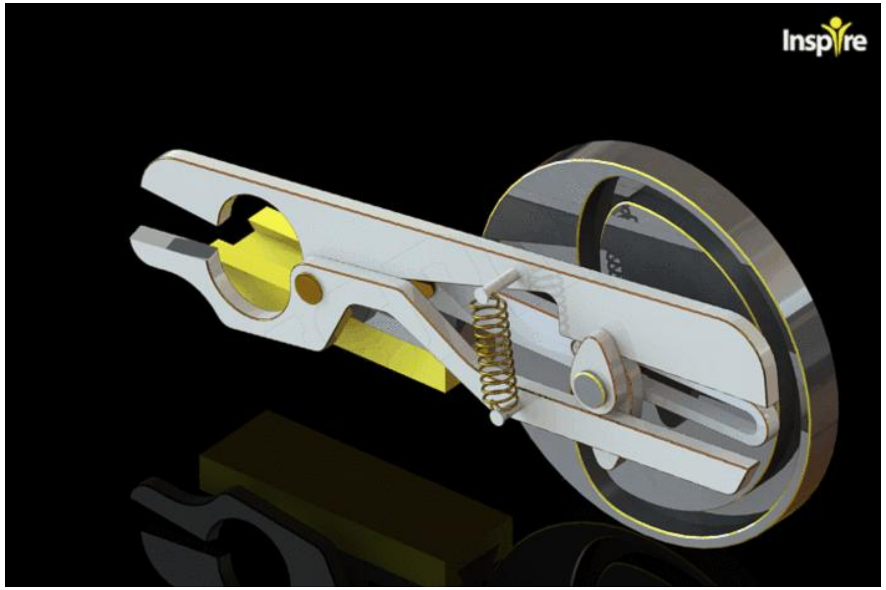
[8] Ye, Z., & Smith, M. R. (2005). Design of a combined cam-linkage mechanism with an oscillating roller follower by an analytical method. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 219(4), 419-427.
[9] Ajith Kumar, G., Ganesan, G., & Sekar, M. (2018). Near perfect path generation of corners chamfered rectangle and single synthesis cam-link mechanism to generate special-slot path. Mechanics Based Design of Structures and Machines, 46(4), 483-498.

2. Design Method

- Compact

  &

- Contained in the trajectory

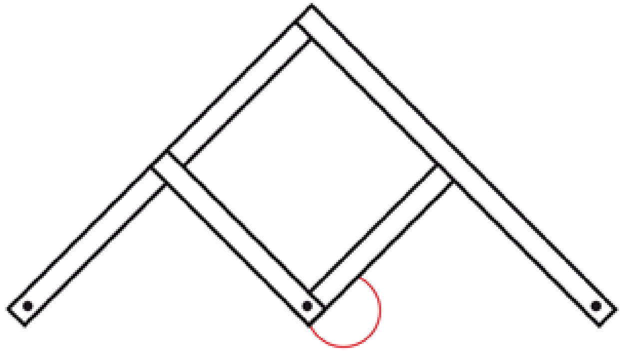


- **Cam:**

  precisely control the motion;

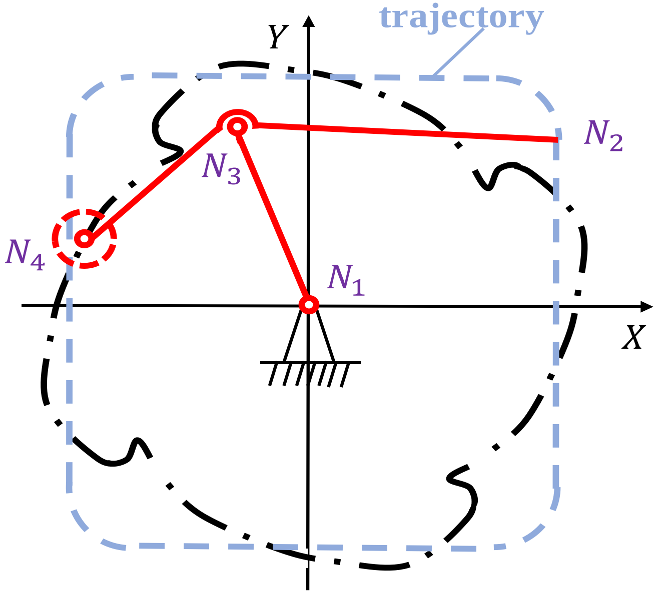
- **Linkages:**

  stroke amplification;

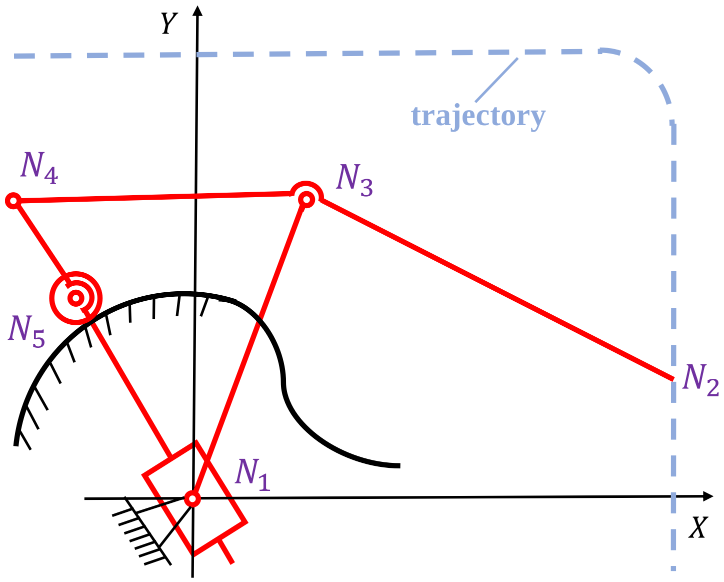


2. Design Method

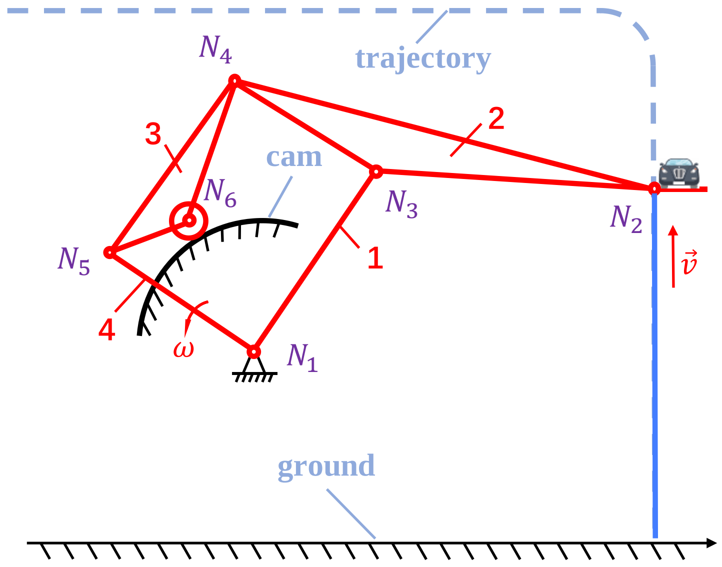
- **Cam-Linkage Mechanism**



I



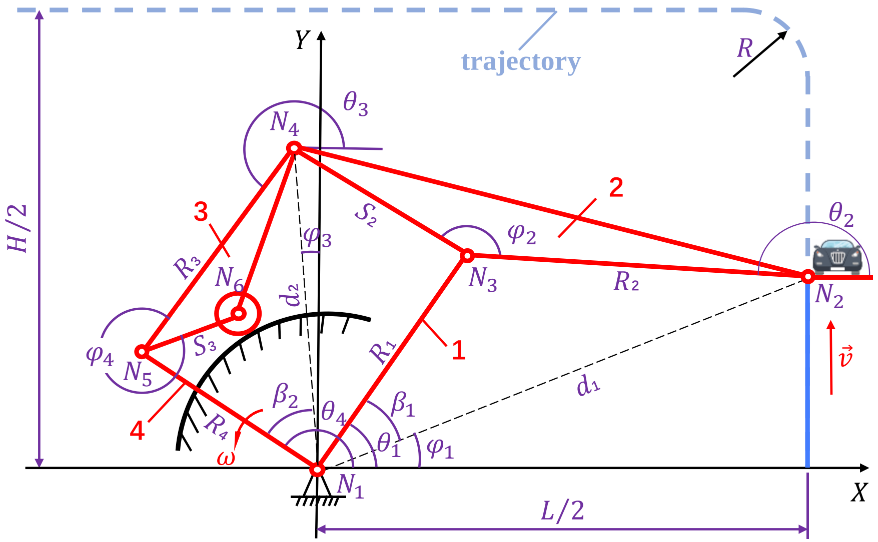
II

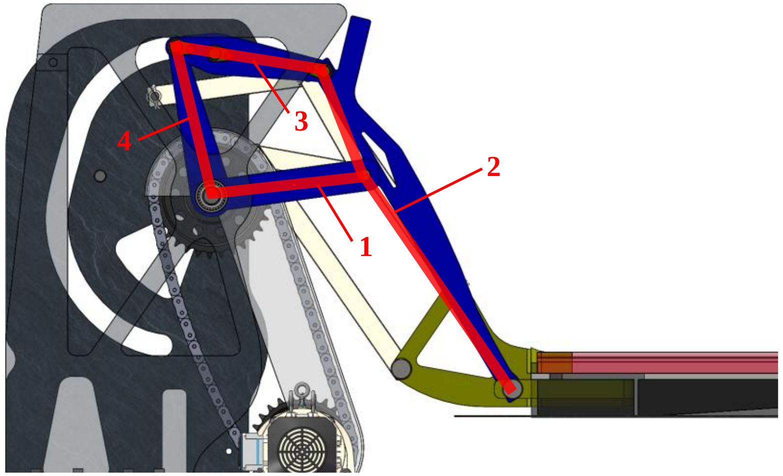


III

2. Design Method

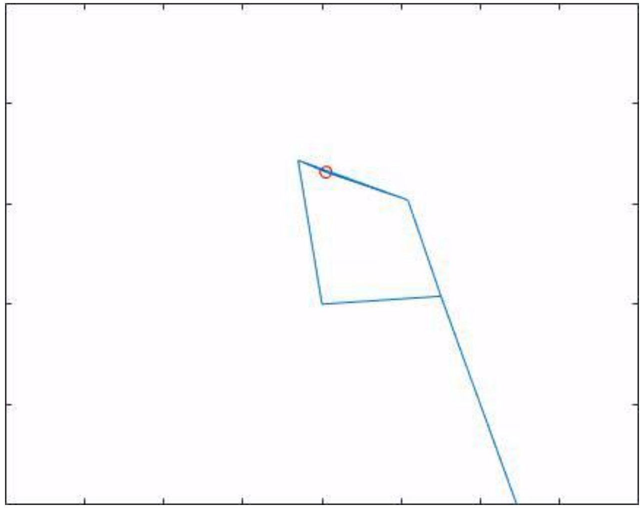
- **Cam-Linkage Mechanism**

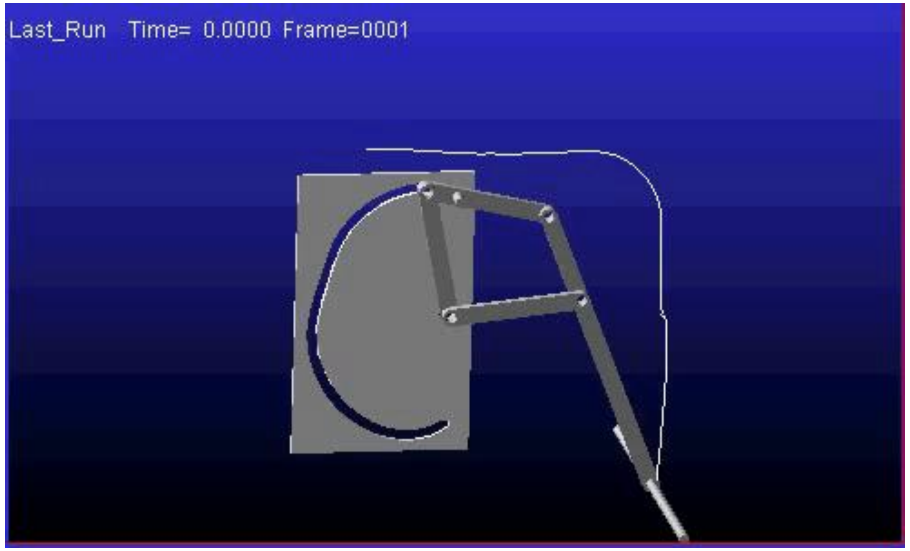


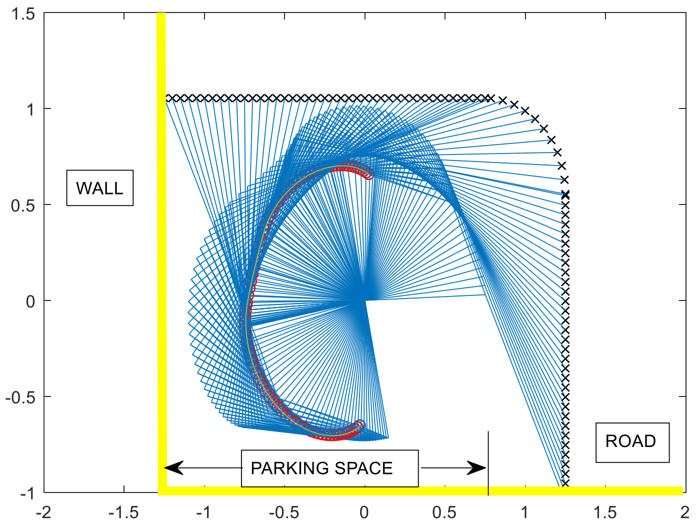


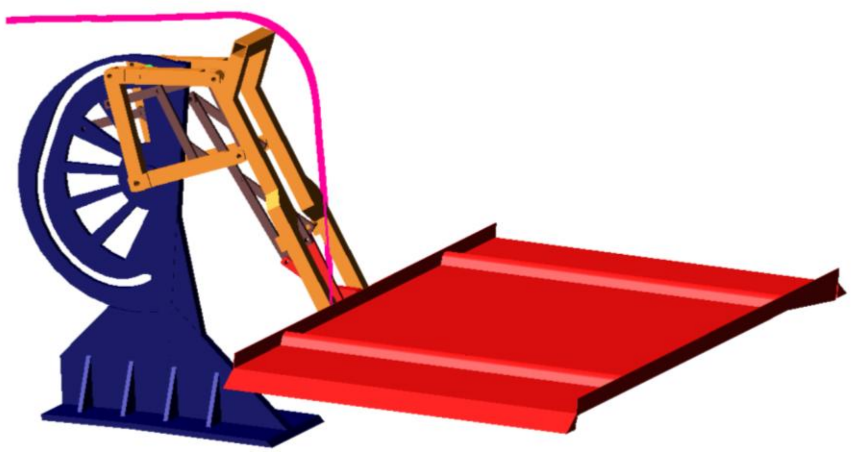
2. Design Method

- **Simulation**





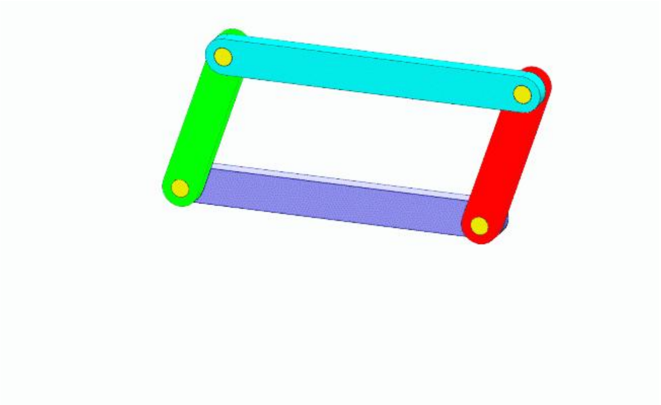




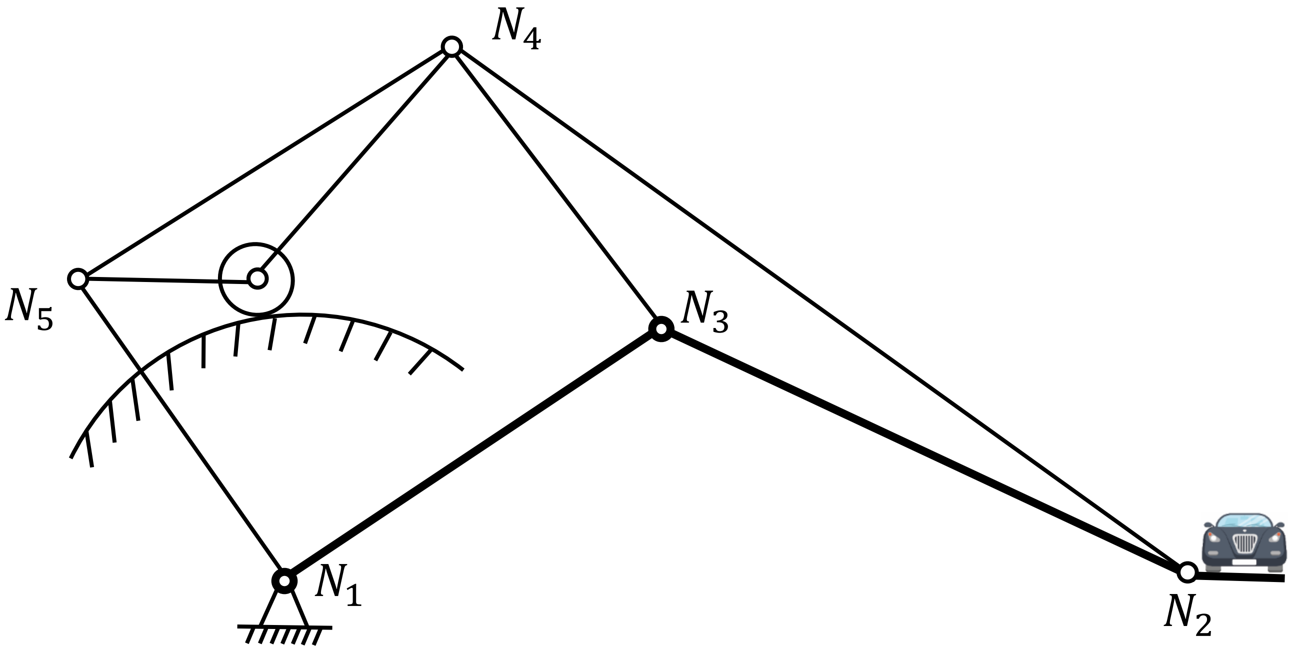
2. Design Method

- **Parking platform:**

  fixed orientation

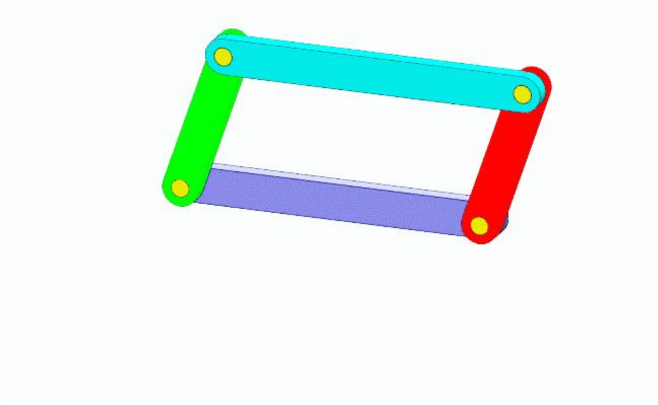


Parallelogram

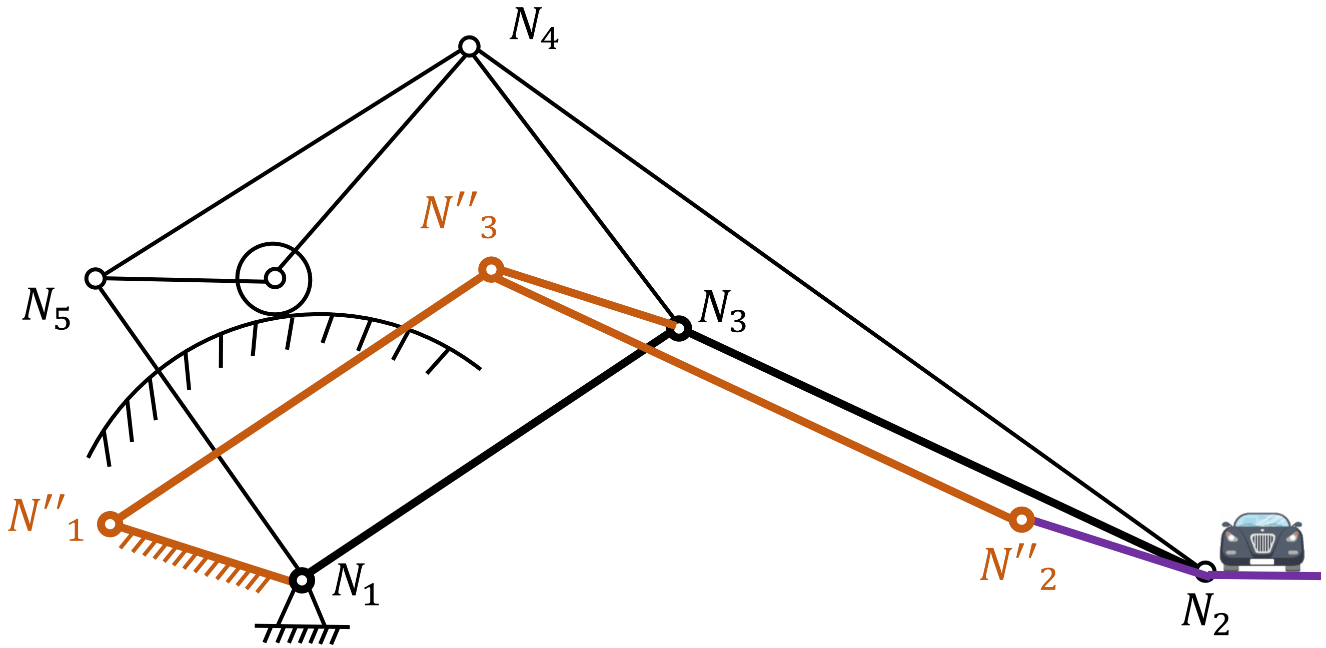


2. Design Method

- **Parking platform:**
  fixed orientation

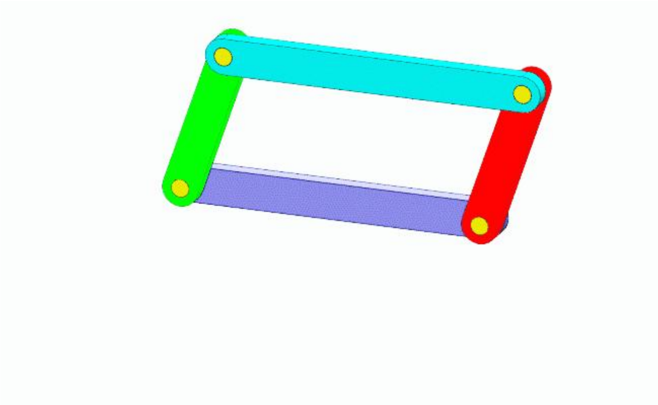


Parallelogram

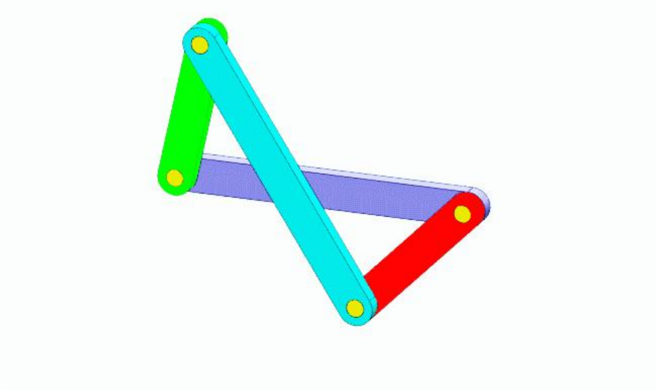


2. Design Method

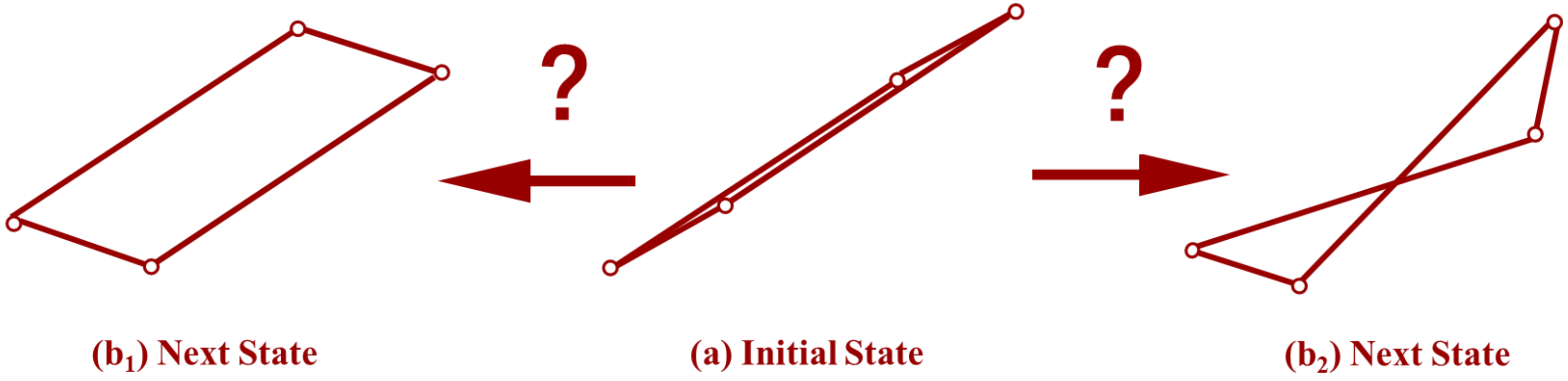
- **Parking platform:**
  fixed orientation



Parallelogram

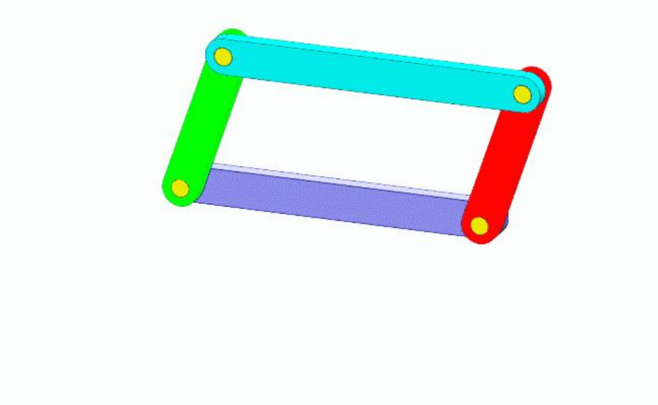


Anti-parallelogram

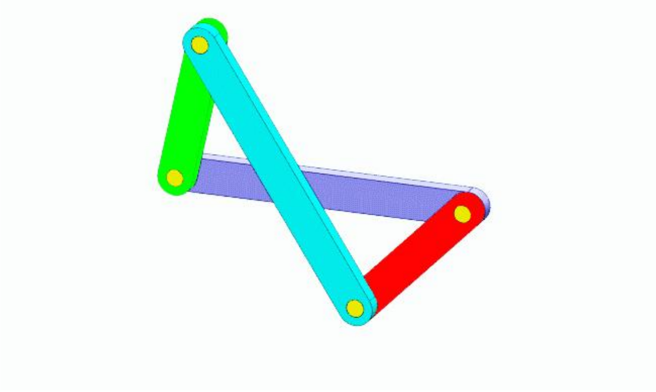


2. Design Method

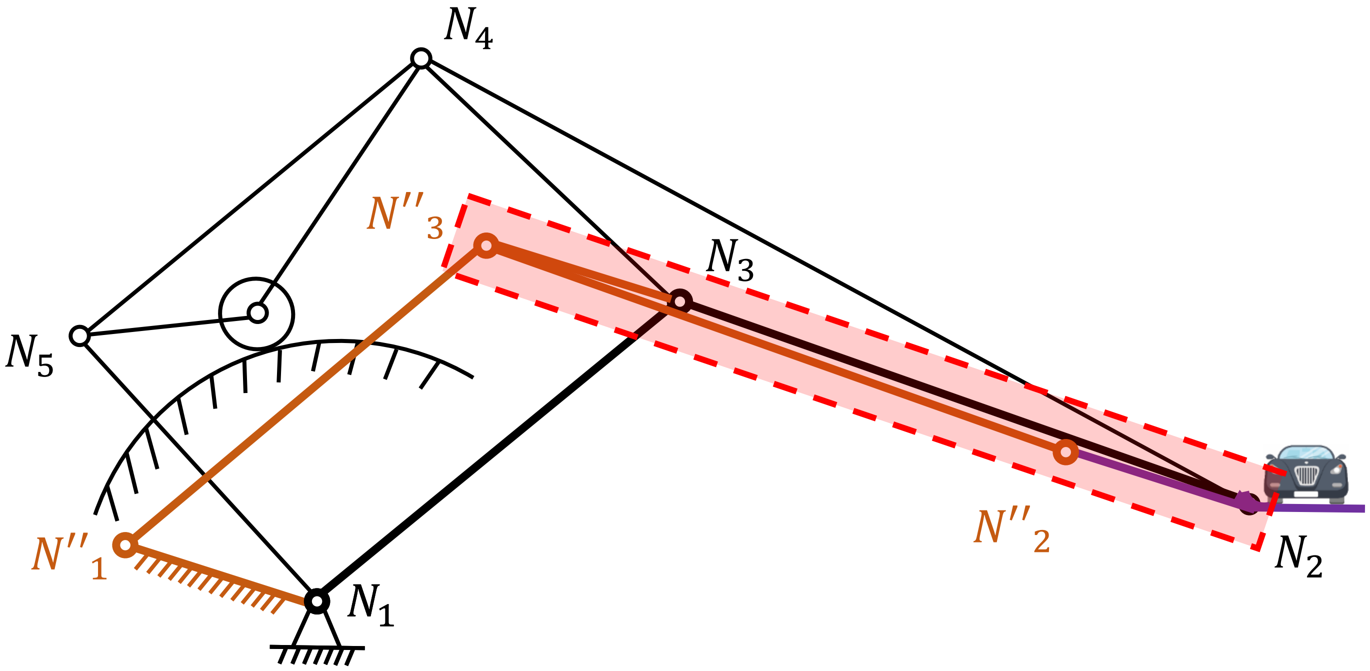
- **Parking platform:**
  fixed orientation



Parallelogram

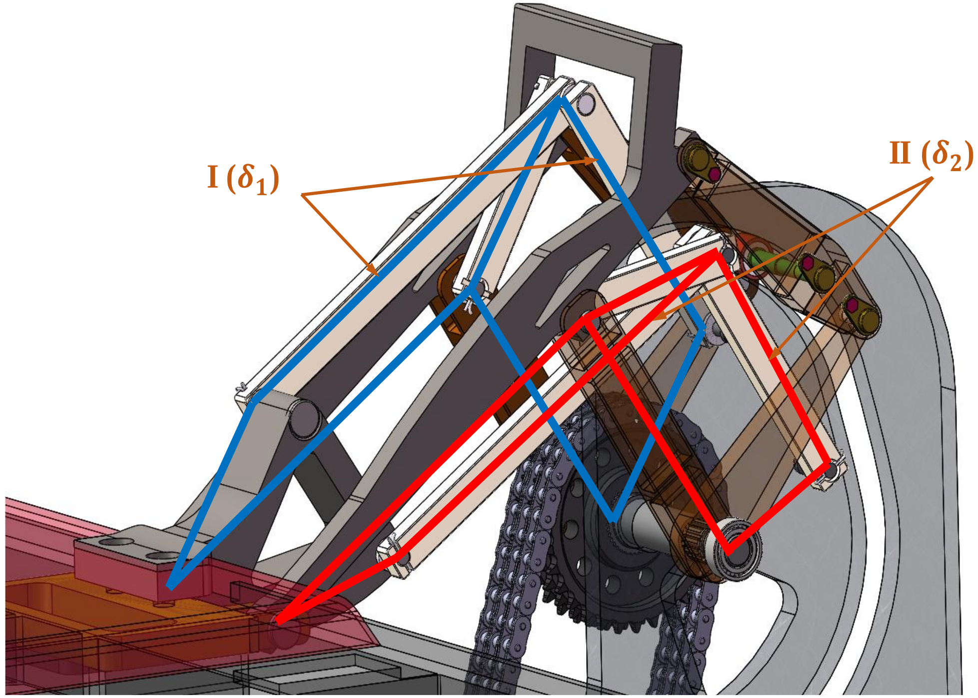


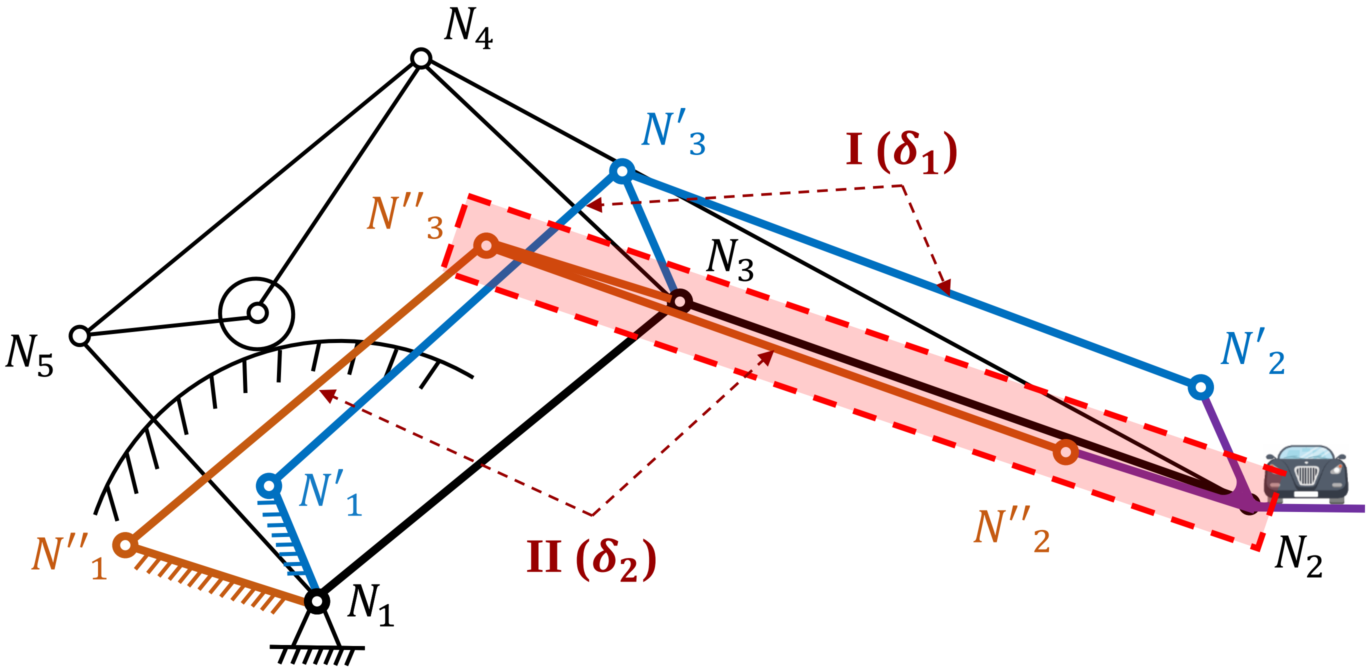
Anti-parallelogram



2. Design Method

- **Parking platform:**
  fixed orientation

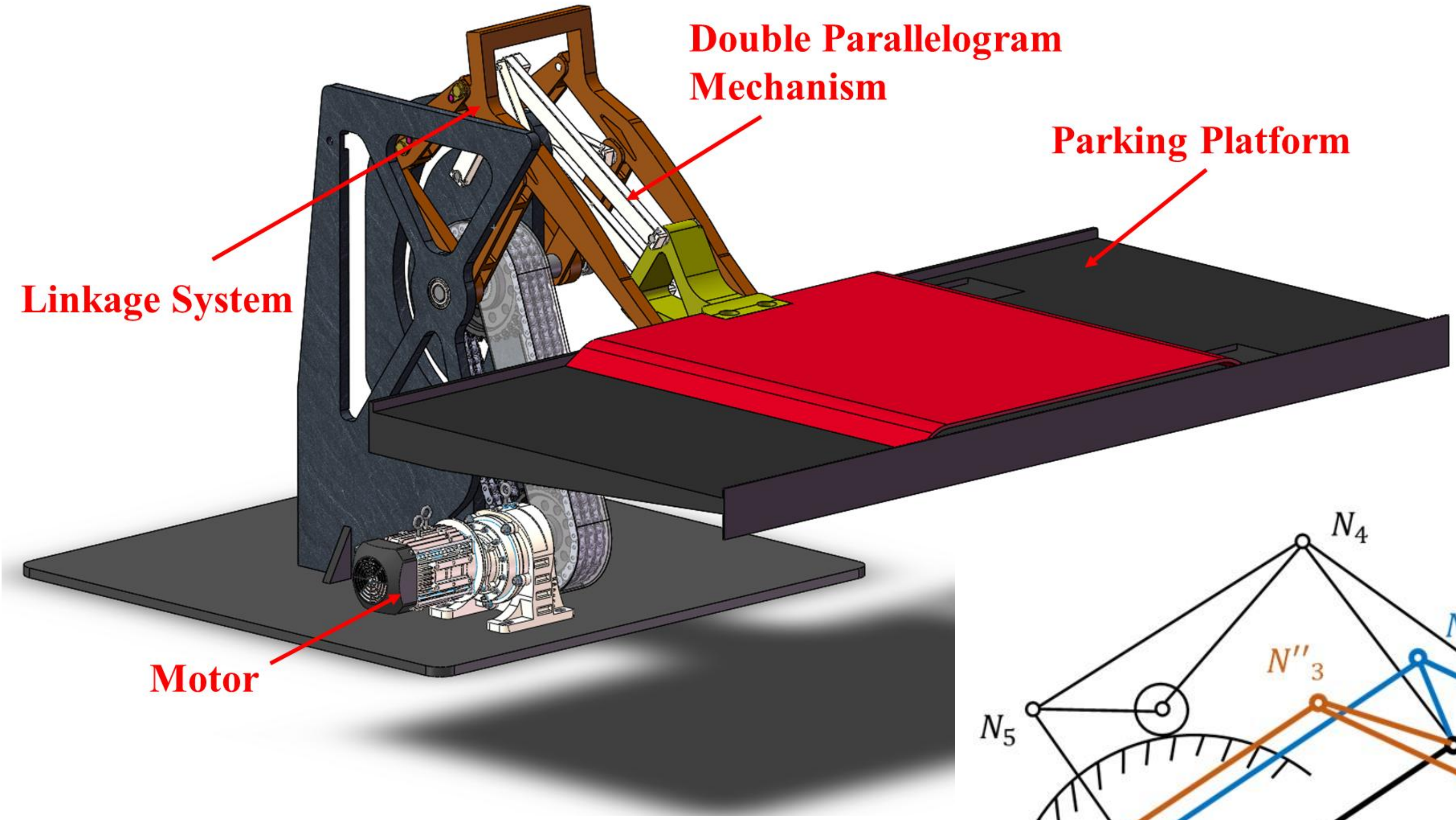


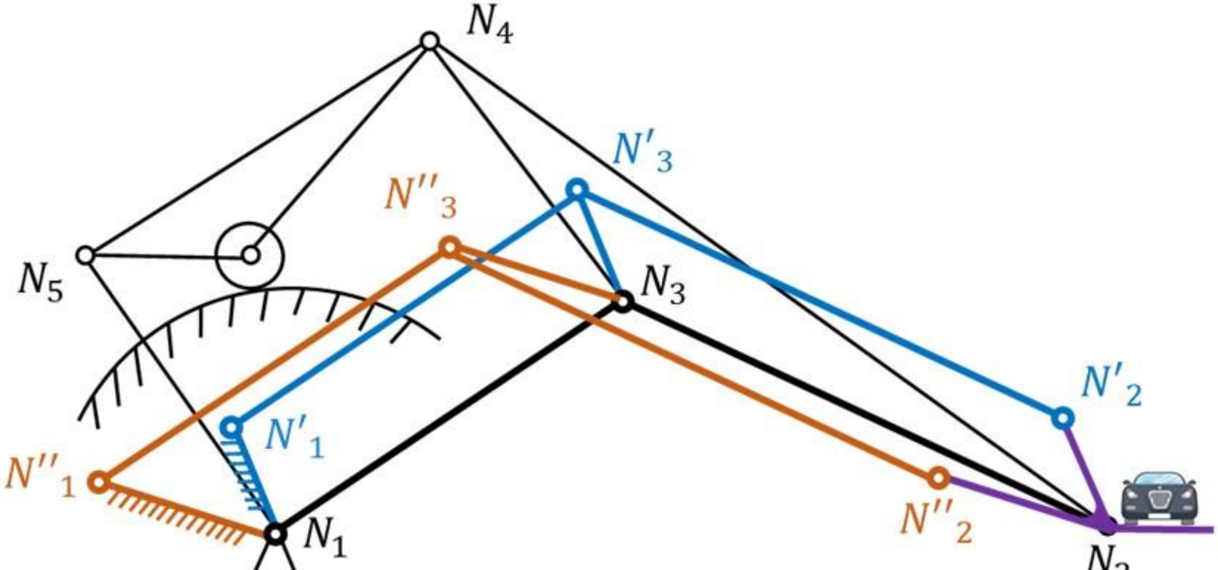


	Group I	Group II
Parallelogram 1	$\square N_2N'_2N'_3N_3$	$\square N_3N''_3N''_2N_2$
Parallelogram 2	$\square N_3N'_3N'_1N_1$	$\square N_3N''_3N''_1N_1$
δ^*	60°	10°

* δ denotes the slant angle of parallelogram mechanism.

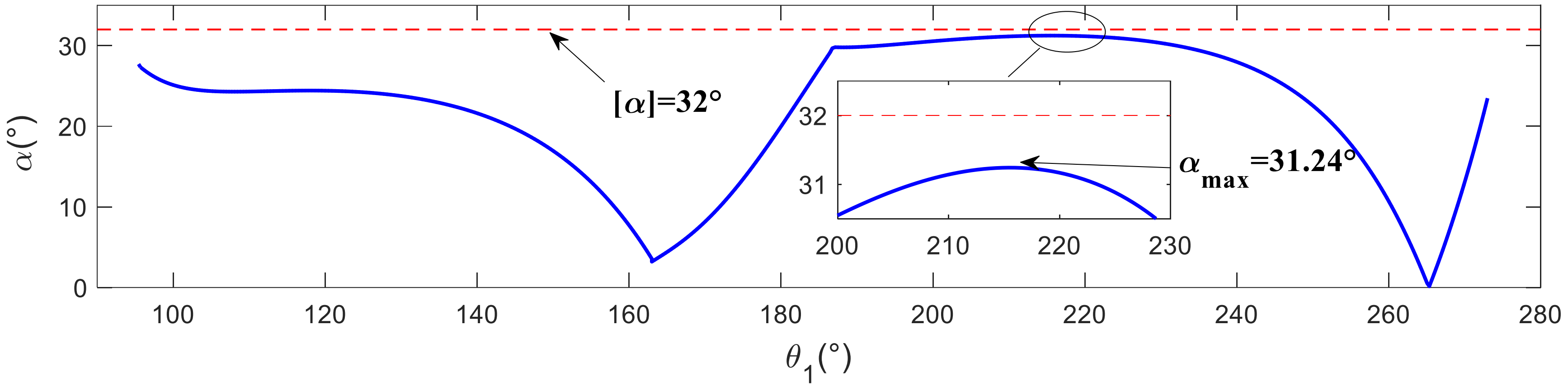
2. Design Method



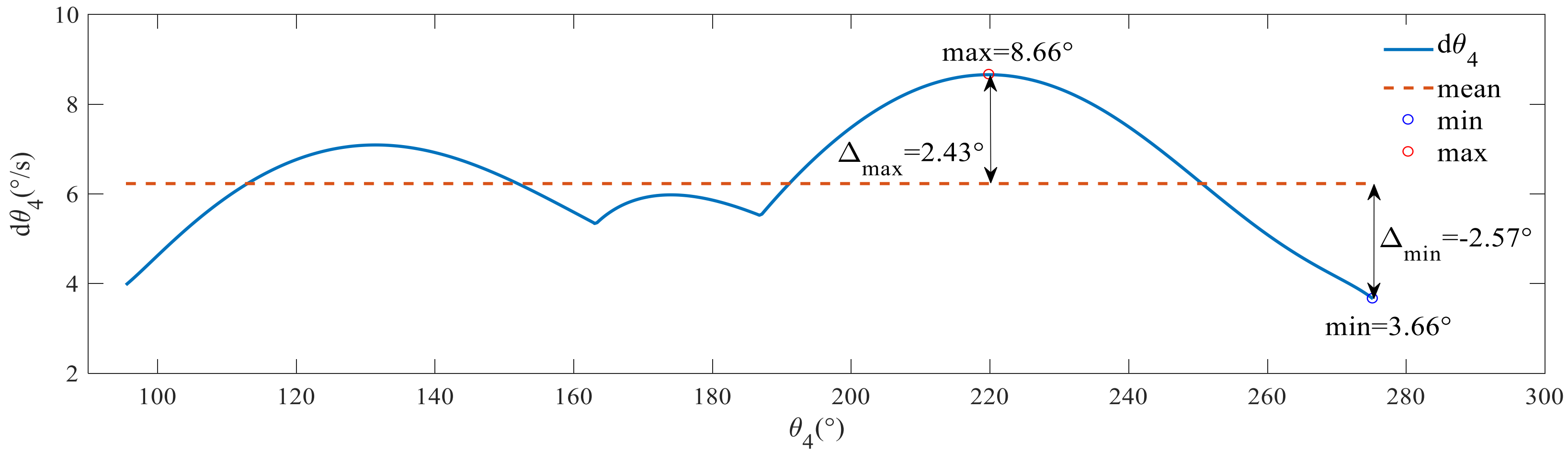


3. Performance Analysis

- **Pressure angle:** $$\alpha' = \left| \arctan \frac{y_{N_6} - y_{N_5}}{x_{N_6} - x_{N_5}} - \arctan \frac{\dot{y}_{N_6}}{\dot{x}_{N_6}} \right| \qquad \alpha = \begin{cases} \alpha' & \alpha' \le 90^\circ \\ 180^\circ - \alpha' & \alpha' > 90^\circ \end{cases}$$



- **Velocity variability:** $$\Delta V = \frac{V_{\max} - V_{\min}}{V_{\max} + V_{\min}} \times 100\%$$



Design of a Novel Cam-Linkage Double Parallelogram Mechanism with Filleted Rectangular Trajectory

Here is a video