Software Lab Computational Engineering Science

Group 12, Pusher Mechanism

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Informatik 12: Software and Tools for Computational Engineering (STCE)
RWTH Aachen University

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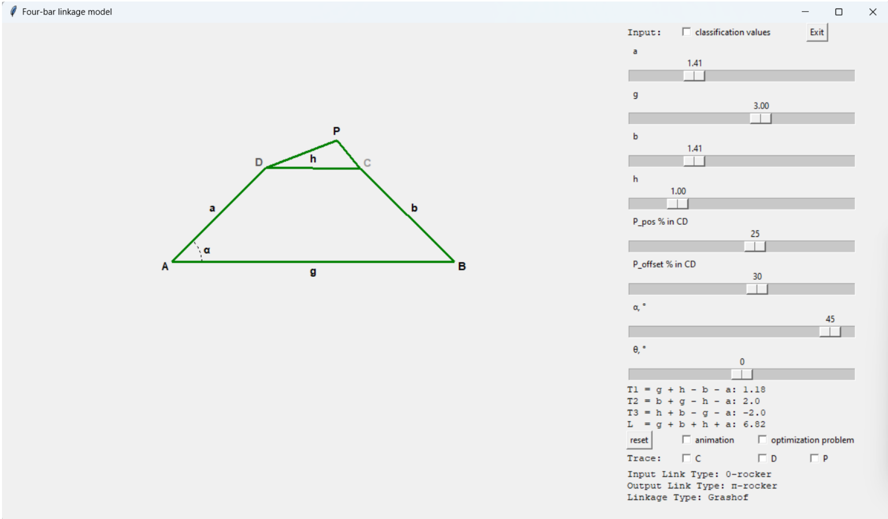
Preface

Four-bar linkage model



Input: □ classification values

a 1.41

g 3.00

b 1.41

h 1.00

P_pos % in CD 25

P_offset % in CD 30

α, ° 45

θ, ° 0

```
T1 = g + h - b - a: 1.18
T2 = b + g - h - a: 2.0
T3 = h + b - g - a: -2.0
L  = g + b + h + a: 6.82
```

reset □ animation □ optimization problem

Trace: □ C □ D □ P

```
Input Link Type: 0-rocker
Output Link Type: π-rocker
Linkage Type: Grashof
```

- **Formular:**

$$M = 3(N - 1 - j) + \sum_{i=1}^{j} f_i$$

  - M: DOF
  - N: Number of links. (4)
  - j: Number of joints. (4 revolute joints)
  - f_i: DOF provided by each joint i, equal 1 for revolute (rotational) joints.
- Calculation for the four-bar linkage:

$$M = \sum_{i=1}^{j} f_i - 3 = 4(1) - 3 = 1$$

- Four-bar linkage has 1 degree of freedom, meaning the mechanism can be fully controlled by a single input. (We use angular velocity as input)

https://en.wikipedia.org/wiki/Degrees_of_freedom_(mechanics)

Introduction

Classification

Grashof's theorem states that a four-bar mechanism has *at least* one revolving link if

$$s + l <= p + q \tag{5-1}$$

and all three mobile links will rock if

$$s + l > p + q \tag{5-2}$$

The inequality 5-1 is **Grashof's criterion**.

All four-bar mechanisms fall into one of the four categories listed in Table 5-1:

Case	l + s vers. p + q	Shortest Bar	Type
1	<	Frame	Double-crank
2	<	Side	Rocker-crank
3	<	Coupler	Doubl rocker
4	=	Any	Change point
5	>	Any	Double-rocker

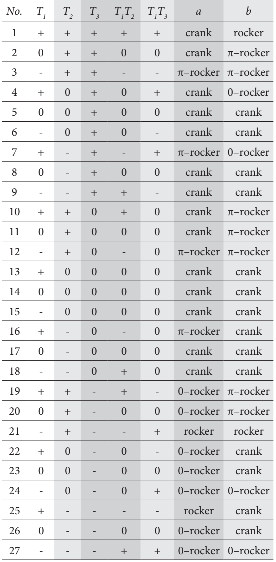
Table 5-1 Classification of Four-Bar Mechanisms

https://www.cs.cmu.edu/~rapidproto/mechanisms/chpt5.html

Analysis

User Requirements

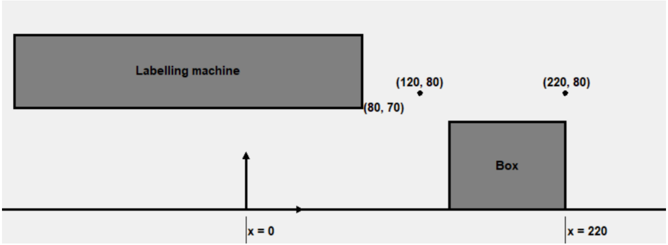
- Implement 27 motion types of the four-bar linkage with one bar fixed:
  - Classification values:
    - $T_1 = g + h - b - a$
    - $T_2 = b + g - h - a$
    - $T_3 = h + b - g - a$
- Implement GUI with motion animation and the ability to choose geometrical parameters:
  - Length of the bars
  - Position of the coupler
  - Input angle
  - Angle relative to the horizon
  - Classification values as alternative input



No.	T_1	T_2	T_3	T_1T_2	T_1T_3	*a*	*b*
1	+	+	+	+	+	crank	rocker
2	0	+	+	0	0	crank	π–rocker
3	-	+	+	-	-	π–rocker	π–rocker
4	+	0	+	0	+	crank	0–rocker
5	0	0	+	0	0	crank	crank
6	-	0	+	0	-	crank	crank
7	+	-	+	-	+	π–rocker	0–rocker
8	0	-	+	0	0	crank	crank
9	-	-	+	+	-	crank	crank
10	+	+	0	+	0	crank	π–rocker
11	0	+	0	0	0	crank	π–rocker
12	-	+	0	-	0	π–rocker	π–rocker
13	+	0	0	0	0	crank	crank
14	0	0	0	0	0	crank	crank
15	-	0	0	0	0	crank	crank
16	+	-	0	-	0	π–rocker	crank
17	0	-	0	0	0	crank	crank
18	-	-	0	+	0	crank	crank
19	+	+	-	+	-	0–rocker	π–rocker
20	0	+	-	0	0	0–rocker	π–rocker
21	-	+	-	-	+	rocker	rocker
22	+	0	-	0	-	0–rocker	crank
23	0	0	-	0	0	0–rocker	crank
24	-	0	-	0	+	0–rocker	0–rocker
25	+	-	-	-	-	rocker	crank
26	0	-	-	0	0	0–rocker	crank
27	-	-	-	+	+	0–rocker	0–rocker

Figure from "Classification, geometrical and kinematic analysis of four-bar linkages" 10.15308/Sinteza-2018-261-266 by Ivana Cvetkovic et al.

User Requirements



- Solve an optimization problem:
  - Push box with size 80×60 from $x = 220$ to $x = 0$
  - Do not cross the area of the labelling machine (Area with $x < 80$ and $y > 70$).
  - Pass above points $(120, 80)$ and $(220, 80)$

System Requirements

Functional

- **Four-bar linkage model**:
  - System simulates all the motion types of the four-bar linkage.
  - System does not crash with any input of geometrical configuration.
- **Tests**:
  - Implement test cases for geometry.
  - Implement test cases with bad input to test system stability.
- **Graphical User Interface**:
  - GUI provides the four-bar linkage visualization and motion animation.
  - User can input geometrical data by moving a point on a slide bar.
  - GUI is coupled with the four-bar linkage model to use implemented motion cases for animation.
  - GUI provides tracing for trajectories of the points.
  - GUI classifies of the linkage.
- **Optimization problem**:
  - It should be possible to find a solution (manually) for the optimization problem using the four-bar linkage model.
  - GUI visualizes the solution.

System Requirements

Non-Functional

- **Performance**:
  - The four-bar linkage model is fast enough to provide smooth GUI animations.
  - GUI animations are not slower than 30 frames per second.
- **Usability**:
  - Every essential part of the four-bar linkage model is well documented.
  - GUI is easy to operate and all functionalities are self-explanatory.
  - GUI source code is well documented.

Design

Principal Components and Third-Party Software

Design

Class Model(s)

Implementation

Development Infrastructure

- **1. Operating System:**
  - Xubuntu/Windows
- **2. Developing Environment:**
  - Programming Language: Python.
  - IDE: Spyder/Pycharm.
  - Package Manager: Anaconda.
- **3. Libraries:**
  - Frontend: tkinter, math, numpy
  - Backend: math, numpy
- **4. Version Control System:**
  - GitHub: Remote code repositories for team collaboration, code reviews, and version control.
    `https://github.com/einsflash/Project_Pusher_Mechanism`
- **5. Frameworks:**
  - Pdoc: Used for generating project documentation, helping the team understand and maintain the code better.
  - Makefile: For build management.

Implementation

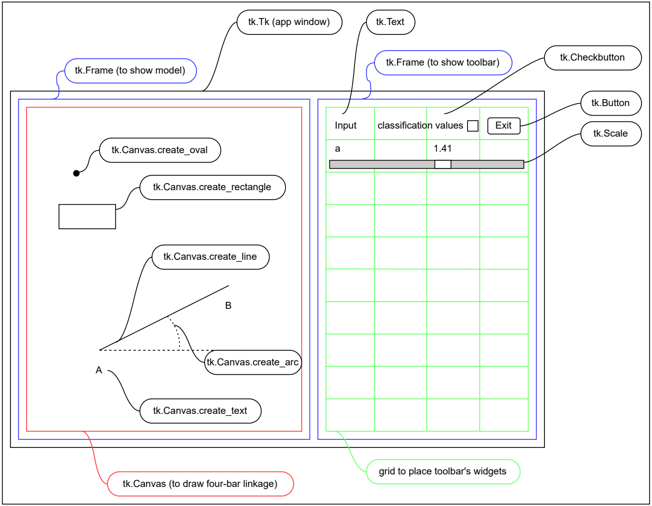
Four-Bar Linkage Model

Implementation

Software Tests

Implementation

GUI, Tkinter Intro



- Initiate all tkinter objects inside GUI class and generate app window:

  GUI().tk.mainloop()

Implementation

GUI, Animation

- Update objects in tk.Canvas every animation step using coords and/or itemconfigure for optimization

```
class GUI:
    def __init__(self):
        ...
        self.init_toolbar()
        ...
    def init_toolbar(self):
        ...
        self.enable_animation = tk.IntVar()
        self.animation_button = tk.Checkbutton(self.toolbar_frame, text=”animation”,
                                               variable=self.enable_animation,
                                               onvalue=1, offvalue=0, command=self.animation)
        self.animation_button.grid(sticky=”W”, row=10, column=2)
        ...
    def refresh(self):
        ...
        self.linkage.run()
        ...
        self.update_linkage_display()
    def animation(self):
        self.run_animation()
    def run_animation(self):
        if self.enable_animation.get():
            self.linkage.animation_alpha() # alpha = alpha + d_alpha
            self.refresh()
            self.tk.after(25, self.run_animation)
    def update_linkage_display(self):
        ...
        self.model_animation.coords(self.model_animation.AB_line, [A_x, A_y, B_x, B_y])
        ...
```

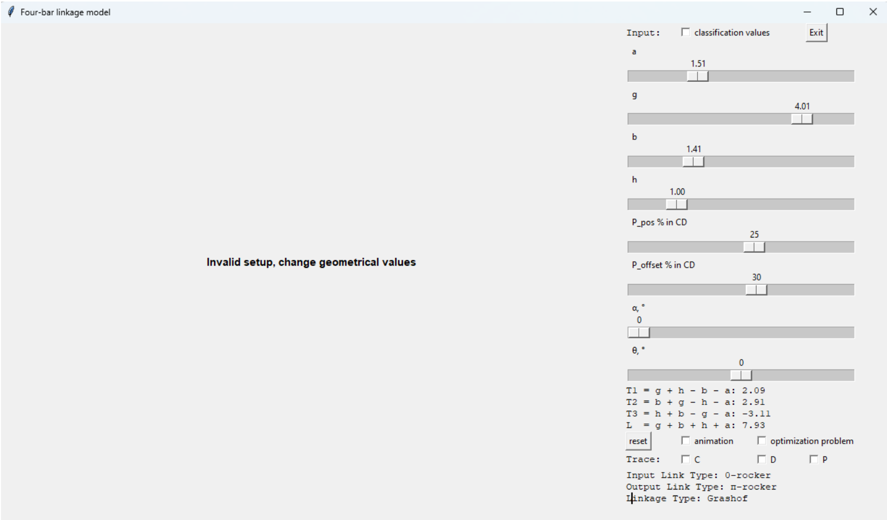
Implementation

GUI, Show and hide objects

- To display different modes, some objects have to be hidden or shown.
- For objects in tk.Canvas use itemconfigure:
  - Hide:
    self.model_animation.itemconfigure(self.model_animation.AB_line, state='hidden')
  - Show:
    self.model_animation.itemconfigure(self.model_animation.AB_line, state='normal')
- For widgets like tk.Scale or tk.Text:
  - Hide: self.slider_T1.grid_remove()
  - Show: self.slider_T1.grid()

Implementation

GUI, Invalid Setup Handling



Invalid setup, change geometrical values

□ classification values

a: 1.51

g: 4.01

b: 1.41

h: 1.00

P_pos % in CD: 25

P_offset % in CD: 30

α, °: 0

θ, °: 0

```
T1 = g + h - b - a: 2.09
T2 = b + g - h - a: 2.91
T3 = h + b - g - a: -3.11
L  = g + b + h + a: 7.93
```

□ animation □ optimization problem

Trace: □ C □ D □ P

```
Input Link Type: 0-rocker
Output Link Type: π-rocker
Linkage Type: Grashof
```

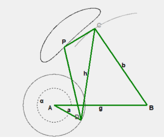
Implementation

GUI, Invalid Setup Handling

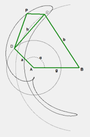
```
class GUI:
    def __init__(self):
        ...
        self.init_linkage_display()
        ...
    ...
    def init_linkage_display(self):
        self.model_animation.invalid_text = self.model_animation.create_text(round(self.model_animation.width/2),
                                                                             round(self.model_animation.height/2),
                                                                             text="Invalid setup, change geometrical values",
                                                                             fill="black", font=('Helvetica 11 bold'))
        self.model_animation.itemconfigure(self.model_animation.invalid_text, state='hidden')
        ...
    ...
    def update_linkage_display(self):
        if self.linkage.geometric_Validity:
            self.show_linkage()
            if self.enable_optimization_problem.get():
                self.show_optimization_problem()
            self.model_animation.itemconfigure(self.model_animation.invalid_text, state='hidden')
        else:
            self.hide_linkage()
            self.hide_optimization_problem()
            self.model_animation.itemconfigure(self.model_animation.invalid_text, state='normal')
            return
        ...
```

Results

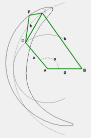
27 movement types



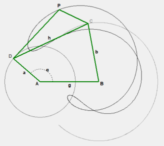
$T_{1,2,3} = 1.0, 1.0, 1.0$



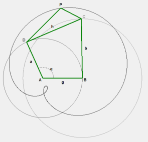
$T_{1,2,3} = 0.0, 1.0, 1.0$



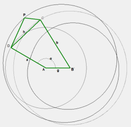
$T_{1,2,3} = -1.0, 1.0, 1.0$



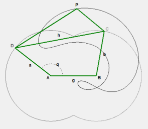
$T_{1,2,3} = 1.0, 0.0, 1.0$



$T_{1,2,3} = 0.0, 0.0, 1.0$



$T_{1,2,3} = -1.0, 0.0, 1.0$



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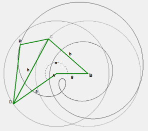
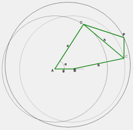
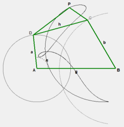


$T_{1,2,3} = 0.0, -1.0, 1.0$



$T_{1,2,3} = -1.0, -1.0, 1.0$



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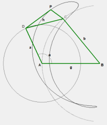
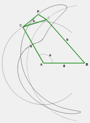
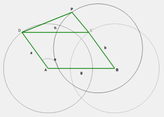


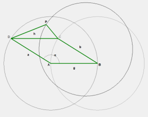
$T_{1,2,3} = 0.0, 1.0, 0.0$



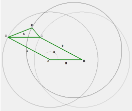
$T_{1,2,3} = -1.0, 1.0, 0.0$



$T_{1,2,3} = 1.0, 0.0, 0.0$



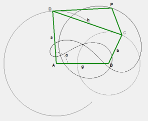
$T_{1,2,3} = 0.0, 0.0, 0.0$



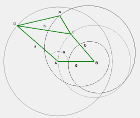
$T_{1,2,3} = -1.0, 0.0, 0.0$

Results

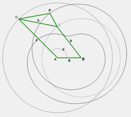
27 movement types



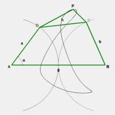
$T_{1,2,3} = 1.0, -1.0, 0.0$



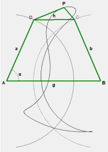
$T_{1,2,3} = 0.0, -1.0, 0.0$



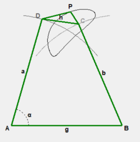
$T_{1,2,3} = -1.0, -1.0, 0.0$



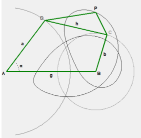
$T_{1,2,3} = 1.0, 1.0, -1.0$



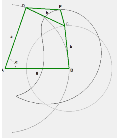
$T_{1,2,3} = 0.0, 1.0, -1.0$



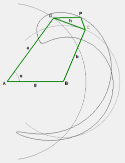
$T_{1,2,3} = -1.0, 1.0, -1.0$



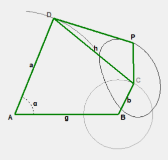
$T_{1,2,3} = 1.0, 0.0, -1.0$



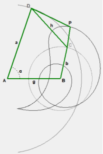
$T_{1,2,3} = 0.0, 0.0, -1.0$



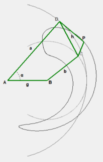
$T_{1,2,3} = -1.0, 0.0, -1.0$



$T_{1,2,3} = 1.0, -1.0, -1.0$



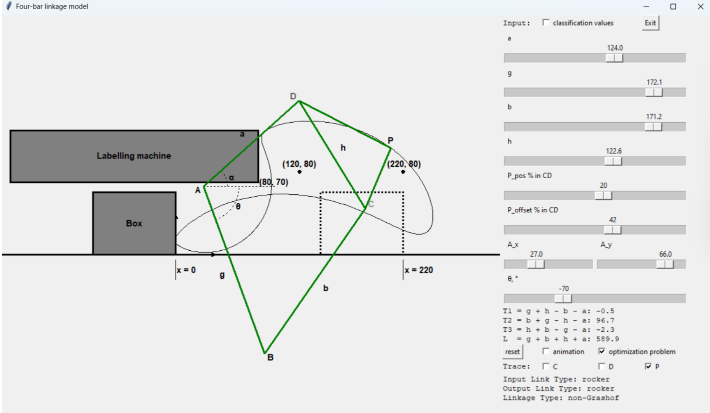
$T_{1,2,3} = 0.0, -1.0, -1.0$



$T_{1,2,3} = -1.0, -1.0, -1.0$

Results

Optimization problem



Four-bar linkage model

Input: □ classification values Exit

a 124.0

g 172.1

b 171.2

h 122.6

P_pos % in CD 20

P_offset % in CD 42

A_x 27.0 A_y 66.0

θ, ° -70

```
T1 = g + h - b - a: -0.5
T2 = b + g - h - a: 96.7
T3 = h + b - g - a: -2.3
L  = g + b + h + a: 589.9
```

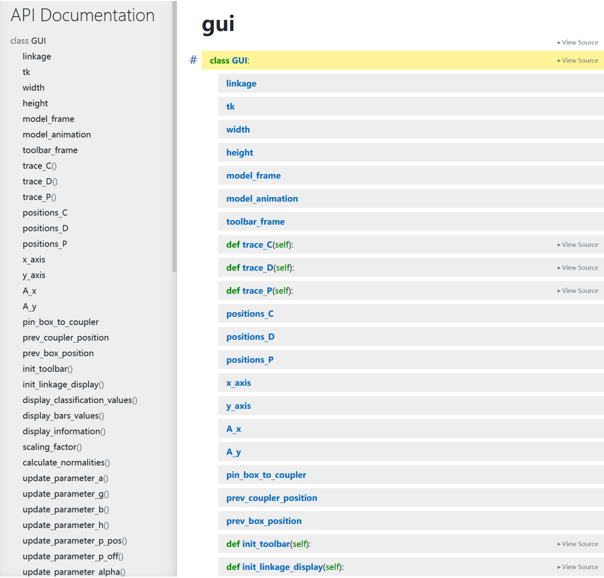
reset □ animation ☑ optimization problem

Trace: □ C □ D ☑ P

```
Input Link Type: rocker
Output Link Type: rocker
Linkage Type: non-Grashof
```

- 9 degrees of freedom (all lengths in cm):
  - Length of four bars: $a = 124.0$, $b = 171.2$, $g = 172.1$, $h = 122.6$.
  - Coupler position: $P_{pos} = 20.0\%$, $P_{offset} = 42.0\%$ of h.
  - Position of point A: $A_x = 27.0$, $A_y = 66.0$.
  - Angle of ground bar relative to horizon: $\theta = -70.0^\circ$

Documentation for Frontend(GUI)



API Documentation

class GUI
- linkage
- tk
- width
- height
- model_frame
- model_animation
- toolbar_frame
- trace_C()
- trace_D()
- trace_P()
- positions_C
- positions_D
- positions_P
- x_axis
- y_axis
- A_x
- A_y
- pin_box_to_coupler
- prev_coupler_position
- prev_box_position
- init_toolbar()
- init_linkage_display()
- display_classification_values()
- display_bars_values()
- display_information()
- scaling_factor()
- calculate_normalities()
- update_parameter_a()
- update_parameter_g()
- update_parameter_b()
- update_parameter_h()
- update_parameter_p_pos()
- update_parameter_p_off()
- update_parameter_alpha()

gui

▸View Source

# **class GUI**: ▸View Source

linkage

tk

width

height

model_frame

model_animation

toolbar_frame

def trace_C(self): ▸View Source

def trace_D(self): ▸View Source

def trace_P(self): ▸View Source

positions_C

positions_D

positions_P

x_axis

y_axis

A_x

A_y

pin_box_to_coupler

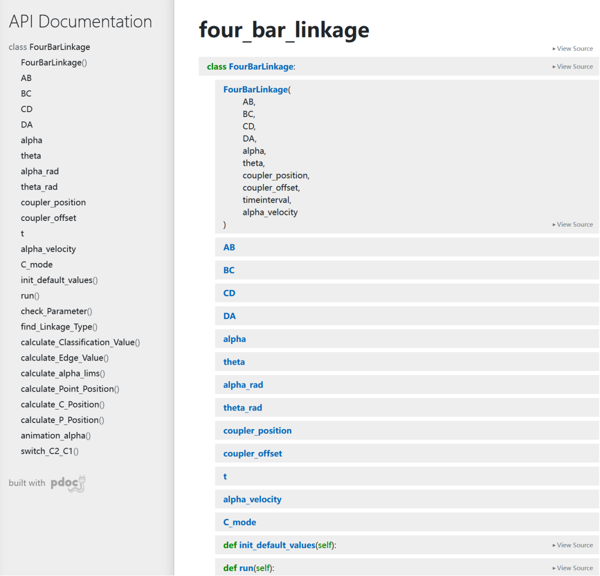
prev_coupler_position

prev_box_position

def init_toolbar(self): ▸View Source

def init_linkage_display(self): ▸View Source

Documentation for Backend



API Documentation

- class FourBarLinkage
  - FourBarLinkage()
  - AB
  - BC
  - CD
  - DA
  - alpha
  - theta
  - alpha_rad
  - theta_rad
  - coupler_position
  - coupler_offset
  - t
  - alpha_velocity
  - C_mode
  - init_default_values()
  - run()
  - check_Parameter()
  - find_Linkage_Type()
  - calculate_Classification_Value()
  - calculate_Edge_Value()
  - calculate_alpha_lims()
  - calculate_Point_Position()
  - calculate_C_Position()
  - calculate_P_Position()
  - animation_alpha()
  - switch_C2_C1()

built with pdoc

four_bar_linkage

▸ View Source

```
class FourBarLinkage:                                ▸ View Source

    FourBarLinkage(
        AB,
        BC,
        CD,
        DA,
        alpha,
        theta,
        coupler_position,
        coupler_offset,
        timeinterval,
        alpha_velocity
    )                                                ▸ View Source

    AB

    BC

    CD

    DA

    alpha

    theta

    alpha_rad

    theta_rad

    coupler_position

    coupler_offset

    t

    alpha_velocity

    C_mode

    def init_default_values(self):                   ▸ View Source

    def run(self):                                   ▸ View Source
```

Project Management

Live Software Demo

Summary and Conclusion

Literature

- Cvetkovic, Ivana and Stojicevic, Misa and Popkonstantinović, Branislav and Cvetković, Dragan. (2018). Classification, geometrical and kinematic analysis of four-bar linkages. 261-266. 10.15308/Sinteza-2018-261-266.