

Teaching materials

Guide notes 0. Introduction to the Platform

MISCE project

Mechatronics for Improving and Standardizing Competences in Engineering



Competence: Mechanical Engineering

Workgroup: Universidad de Castilla-La Mancha



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Mechatronics for Improving and Standardizing Competences in Engineering, MISCE

Competence: Mechanical Engineering

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Introduction to the
Platform

This document corresponds to the introduction lecture, presenting the experimental platform and MATLAB app, for the competence 'Mechanical Engineering' using the 'Four-bar mechanism platform'

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1 Introduction

The proposed lectures consist of three sessions, each dedicated to analysing the position, velocity, and acceleration problems in the kinematic of a four-bar mechanism, one of the most versatile and widely used mechanisms in industry. This mechanism is commonly found in systems such as automobile suspensions, aircraft landing gear, windshield wipers, actuation amplifiers in backhoe buckets, flap deployment mechanisms, door opening mechanisms, steam locomotive transmissions, elliptical bicycles, among other applications.

2 Platform overview

The final aspect of the experimental platform is shown in Figure 1. The setup focuses on the classical four-bar linkage, one of the most studied mechanisms in engineering education.

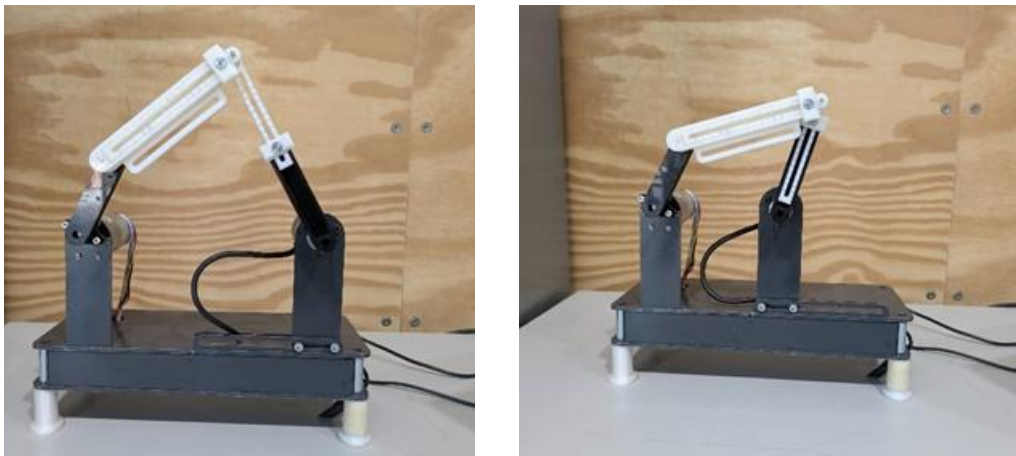


Figure 1. Experimental platform overview

Its main functional elements consist of:

- A modular four-bar mechanism with adjustable link length.
- A DC-motor w/encoder to actuate the input link (crank).
- An optical encoder placed at the output link (rocker) to measure motion response.
- A control unit based on ESP32 for real-time data acquisition.
- A user-friendly interface developed in MATLAB® App Designer.

This platform allows experimentation with position, velocity and acceleration analysis under different geometrical setups and control conditions.

2.1 Nomenclature

The four-bar mechanism platform shown in Figure 1 will be used throughout the lectures. As aforementioned in the previous section, three out of the four links are adjustable. In this sense, the fixed link (link 1) length can be selected within the range $\rho_1 \in [105, 185]$ mm, the coupler (link 3) length within the range $\rho_3 \in [110, 195]$ mm and the rocker (link 4) length within the range $\rho_4 \in [85, 150]$ mm, all of them adjusted in 5 mm increments. On the other hand, the crank (link 2) length



is fixed to $\rho_2 = 50$ mm, which is also the link driven by the DC-motor. Figure 2 shows the nomenclature of the platform for better understanding.

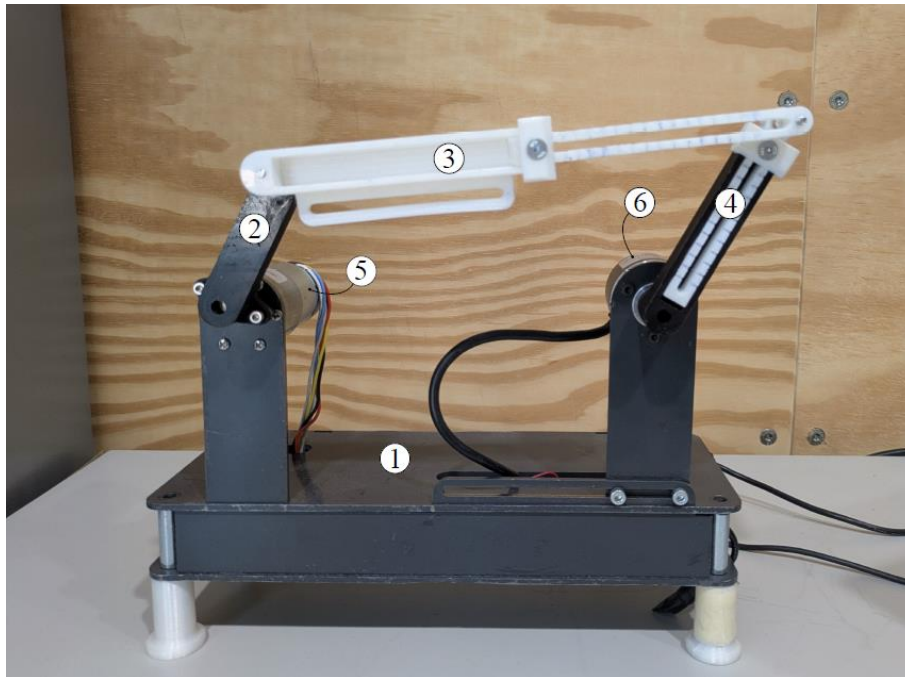


Figure 2. Four-bar mechanism nomenclature

2.2 Mathematical constrains

Figure 3 shows the vectors used for the kinematic analysis of the mechanism. These are the conventional vectors typically used in machine theory literature such as [1,2,3].

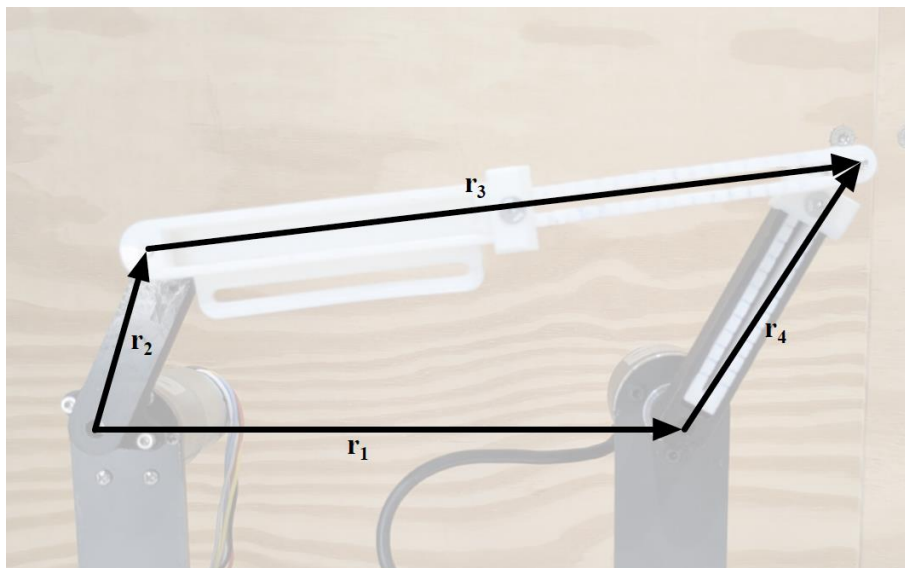


Figure 3. Four-bar mechanism vectorial nomenclature

Since the four-bar mechanism is a planar mechanism, i.e., all its velocities are parallel to a plane, 2D vectors can be used. The fact that only two quantities are needed to describe a 2D vector allows



the use of a well-known mathematical entity: the complex number. Thus, the vector \mathbf{r} can be written as the complex number:

$$\mathbf{r} = \text{Re}(\mathbf{r}) + i \cdot \text{Im}(\mathbf{r}),$$

where:

$$\text{Re}(\mathbf{r}) = \rho \cos(\theta)$$

$$\text{Im}(\mathbf{r}) = \rho \sin(\theta)$$

or in polar form, where the modulus and argument of the complex numbers can be written as:

$$\rho = \sqrt{r_x^2 + r_y^2}$$

$$\theta = \tan^{-1}(r_y/r_x)$$

Using Euler's formula, the complex number \mathbf{r} can also be expressed as:

$$\mathbf{r} = \rho e^{i\theta}$$

This form is particularly useful for differentiation. Its first and second derivatives are:

$$\dot{\mathbf{r}} = \dot{\rho} e^{i\theta} + \rho \omega i e^{i\theta}$$

$$\ddot{\mathbf{r}} = (\ddot{\rho} - \rho \omega^2) e^{i\theta} + (\rho \alpha + 2\dot{\rho} \omega) i e^{i\theta}$$

where ω is the link's angular velocity and α its angular acceleration. These equations can also be rewritten considering that $\mathbf{r} = \rho e^{i\theta}$, and therefore, $\mathbf{r}/\rho = e^{i\theta}$ resulting in:

$$\dot{\mathbf{r}} = (\dot{\rho}/\rho) \mathbf{r} + \omega i \mathbf{r}$$

$$\ddot{\mathbf{r}} = [(\ddot{\rho}/\rho) - \omega^2] \mathbf{r} + [\alpha + 2(\dot{\rho}\omega/\rho)] i \mathbf{r}$$

The kinematic study of a four-bar mechanism includes the analysis of position, velocity, and acceleration, always in that order. To perform these calculations, the dimensions of the links must be known, including the positions of the kinematic pairs. This is the first task in the practical lectures: defining the link dimensions. For the first activity, to proceed correctly, link 2 must be capable of full rotation. This can be verified experimentally using the practice platform by checking if the mechanism jams when attempting to rotate link 2 in a full loop. It can also be verified theoretically using Grashof's law.

Grashof's Law: In a four-bar linkage with one fixed link, if the sum of the shortest link (s) and the longest link (l) is less than or equal to the sum of the other two links (p and q), then at least one of the links will be capable of a full rotation.

Mathematically:

$$s + l \leq p + q$$

Thus, before performing any exercise, the student must define the dimensions of the mechanism. In this guide, as an example, the following dimensions are used:

- Fixed link: $\rho_1 = 140$ mm
- Input link (crank): $\rho_2 = 50$ mm
- Coupler: $\rho_3 = 160$ mm
- Output link (rocker): $\rho_4 = 100$ mm



In this case:

$$\rho_2 + \rho_3 = 50 + 160 = 210 \leq \rho_1 + \rho_4 = 140 + 100 = 240$$

Grashof's condition is satisfied, therefore, the four-bar mechanism will not lock. Students must perform a similar check for the link dimensions they choose along the lectures.

To analyse the kinematics of a one-degree-of-freedom mechanism, it is also necessary to know the angle, angular velocity, and angular acceleration of at least one link. In this case, it will be link 2, which is equipped with a controllable servomotor that can be programmed to provide the required input for the kinematic analysis.



3 App description

When launching the app for managing the platform the following screen will show (see Figure 4):

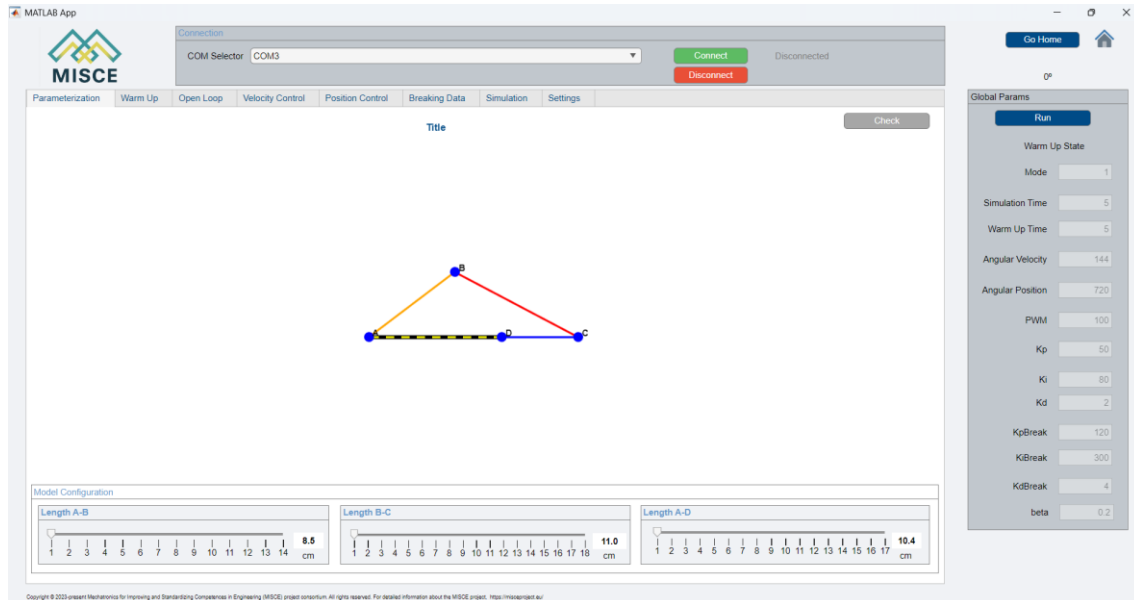


Figure 4. Overall view of the four-bar mechanism control app

In the top part of the screen the user must select the proper serial port and click 'Connect'. When the connection to the platform is established, the connection stage will change to 'Connect'.

At any time, the user can exist the app or stop the experiment by clicking 'Disconnect'.

The rest of the app is divided in 8 tabs, which correspond to the configuration of the four-bar mechanism platform (link's length), 4 different operation modes and the data recording process.

The tabs used for these lectures are described in the following sections.

3.1 Parameterization

First, the configuration of the platform must be selected, i.e. the link's length and position. To set a specific configuration, the user must select the correspondent length and validate the configuration (see Figure 5).

Procedure:

1. Define 'Length A-B', 'Length B-C' and 'Length A-D' by moving the slider.
2. Click on 'Not Validated', which will change to 'Validate'.

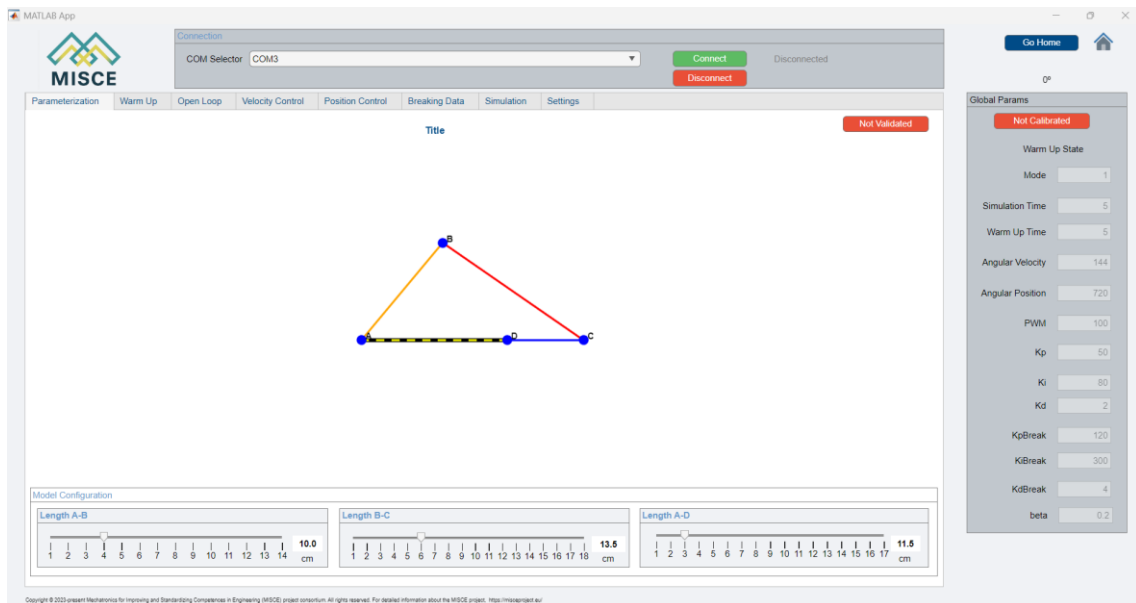


Figure 5. Overview of the Parameterization tab

After this procedure, the mechanism is ready to be calibrated in real life, the user only must click on 'Ready to Calibrate' (see Figure 6).

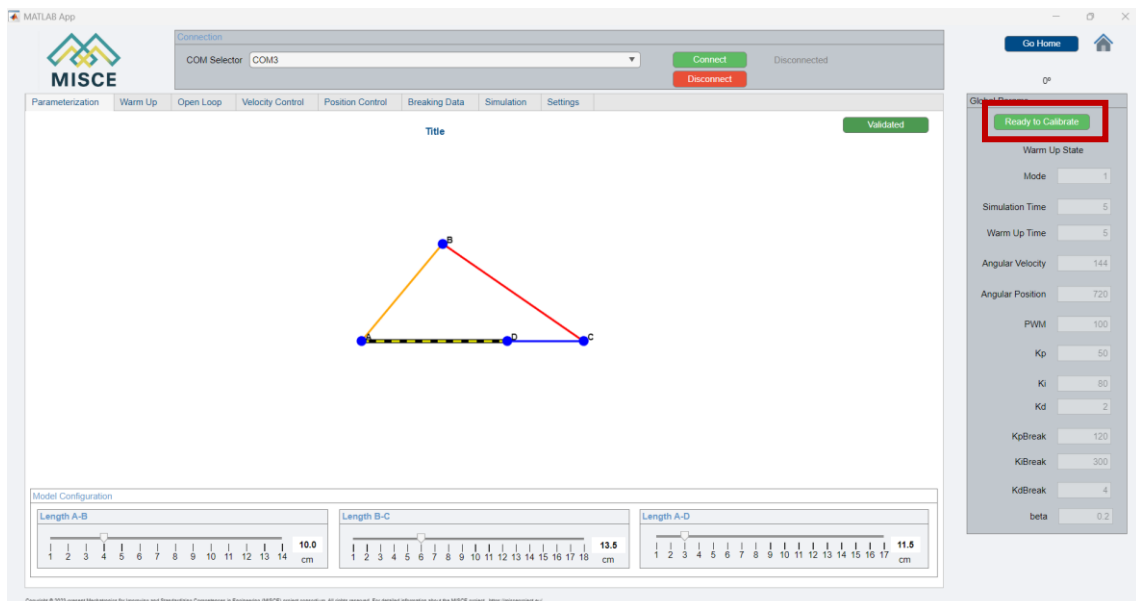


Figure 6. Calibration process of the platform

3.2 Operation mode 1: Warm Up

The four-bar mechanism platform is driven by a DC motor whose dynamic parameters can suffer changes with the temperature. In this way, this operation mode is devoted to warm up the motor making it running during a specific time (see Figure 7).

Procedure:

1. Define 'Warm Up Time' in seconds, e.g. 20 seconds.
2. Define 'PWM' value, e.g. 100 Hz.



3. Run the simulation.

Result:

The shaft of the DC motor will rotate at maximum velocity during the specified time increasing its temperature¹.

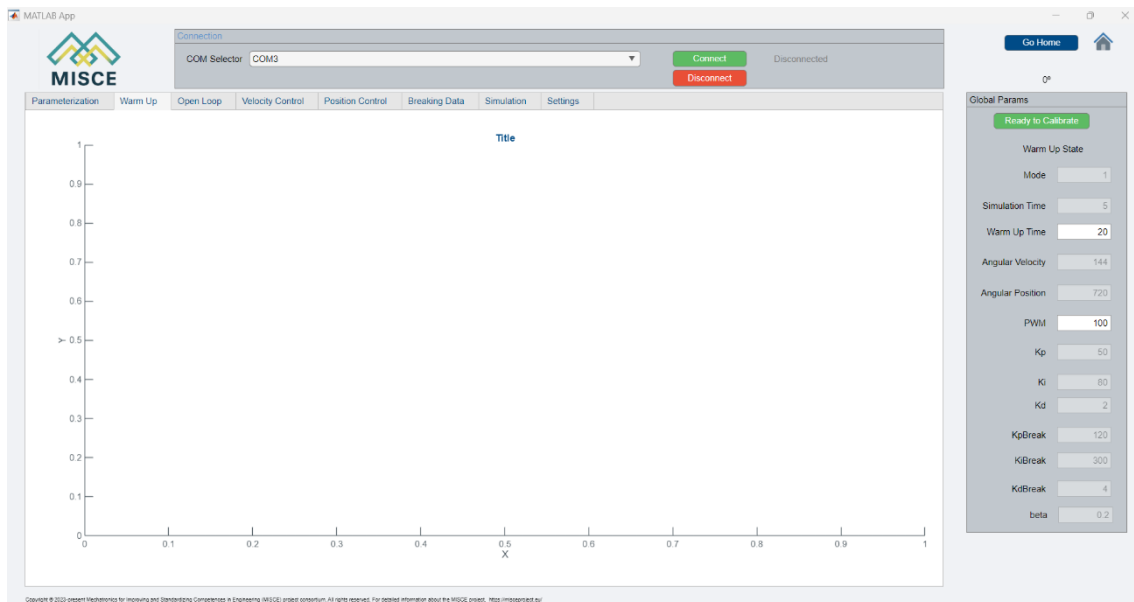


Figure 7. Operation mode 1: Warm Up

3.3 Operation mode 2: Open Loop

The open loop mode is used when there is no need to control the response of the mechanism. This mode is useful when studying the 'natural' dynamic response of a system under different inputs.

The screenshot of this operation mode is shown in Figure 8.

Procedure:

1. Define 'Simulation Time' in seconds, e.g. 10 seconds.
2. Define 'PWM', e.g. 100 Hz.
3. Run the simulation.

Result:

The DC motor will be excited with a step-shaped input and after the experiment time, its position, velocity and acceleration responses could be seen in the 'Breaking Data' tab.

¹ Note: It is recommended to warm the motor up during 20 or 30 seconds prior to the start of any experiment, e.g. velocity or position control (operation modes 2, 3 and 4).

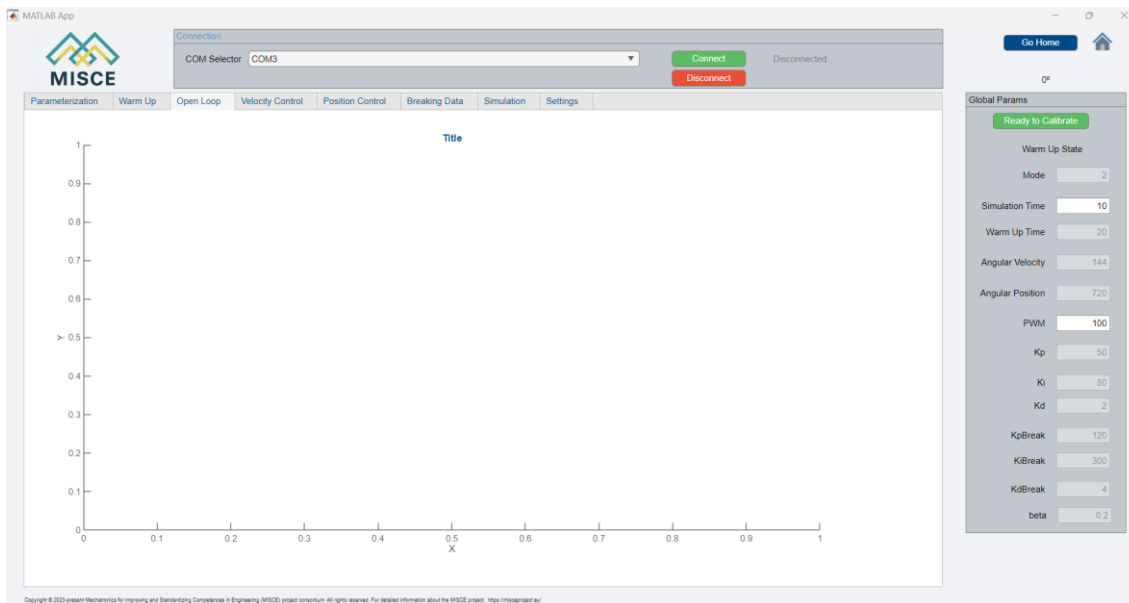


Figure 8. Operation mode 2: Open Loop

3.4 Operation mode 3: Velocity Control

The 'Velocity Control' mode focuses on controlling the angular position of the DC-motor driving the crank of the four-bar mechanism platform.

The screenshot of this operation mode is shown in Figure 9.

Procedure:

1. Define 'Simulation Time' in seconds, e.g. 10 seconds.
2. Define 'Angular Velocity', e.g. 144 rad/s.
3. The parameters of the PID controller, K_p , K_i and K_d are predefined.
4. Run the simulation.

Result:

The DC motor will be controlled in velocity with the specified PID controller and the defined velocity reference and after the experiment time, its position, velocity and acceleration responses could be seen in the 'Breaking Data' tab.

Additionally, in this mode the 'Position Data', the 'Power Signal', i.e. the control signal, and the 'Error Data' could be seen changing to the corresponding tab (see Figure 9).

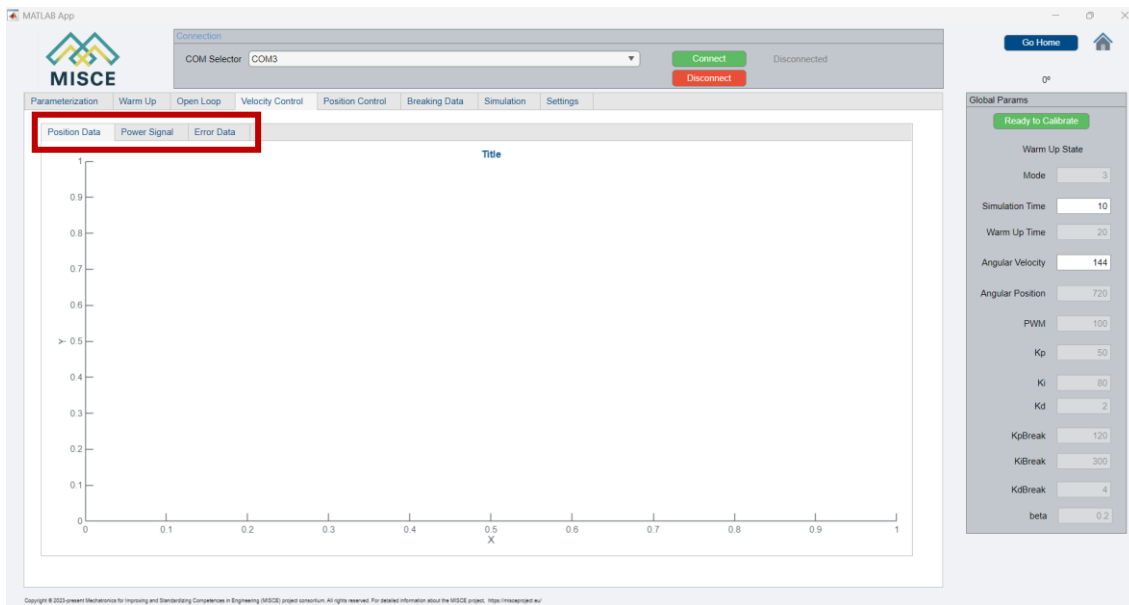


Figure 9. Operation mode 3: Velocity Control

3.5 Operation mode 5: Position Control

The 'Position Control' mode focuses on controlling the angular position of the DC-motor driving the four-bar mechanism crank or input link.

The screenshot of this operation mode is shown in Figure 10.

Procedure:

1. Define 'Simulation Time' in seconds, e.g. 10 seconds.
2. Define 'Angular Position', e.g. 720 rad.
3. The parameters of the PID controller, K_p , K_i and K_d are predefined.
4. Run the simulation.

Result:

The DC motor will be controlled in position with the specified PID controller and the defined position reference and after the experiment time, its position, velocity and acceleration responses could be seen in the 'Breaking Data' tab.

Additionally, in this mode the 'Position Data', the 'Power Signal', i.e. the control signal, and the 'Error Data' could be seen changing to the corresponding tab (see Figure 10).

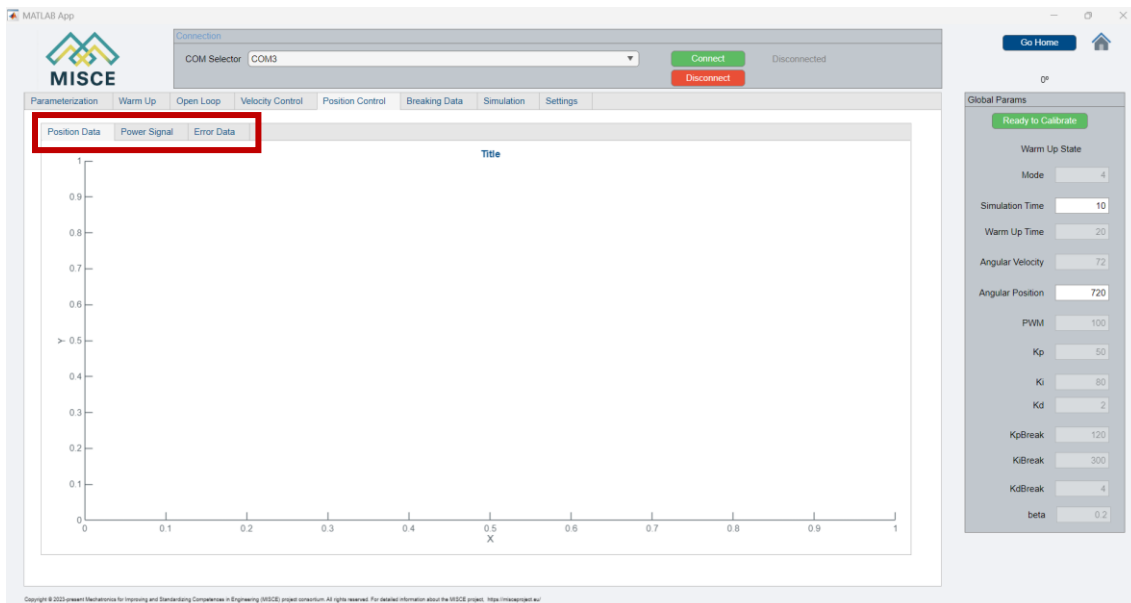


Figure 10. Operation mode 4: Position Control

3.6 Settings

The 'Settings' tab, shown in Figure 11, allows the user three functionalities.

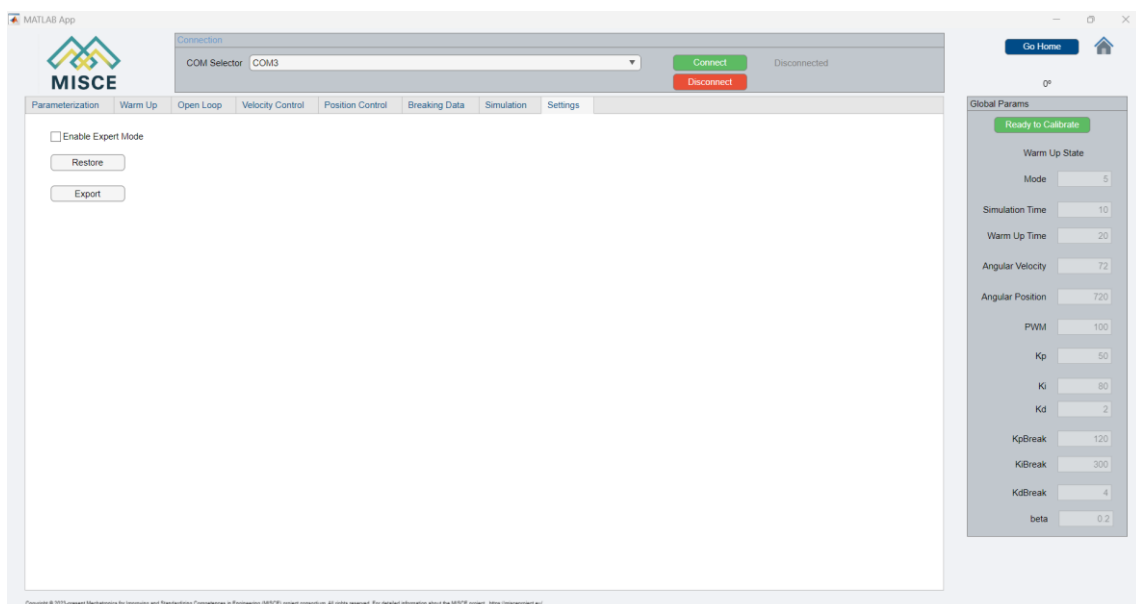


Figure 11. Overview of the Settings tab

The user can change the Global parameters on the 'Global Params' column by ticking the 'Enable Expert Mode' option. Note that changing some of these parameters can generate abnormal DC-motor behaviour (see Figure 12). However, it could be interesting for the user changing the PID parameters, K_p , K_i and K_d , and adjust them to the experiments to be performed.

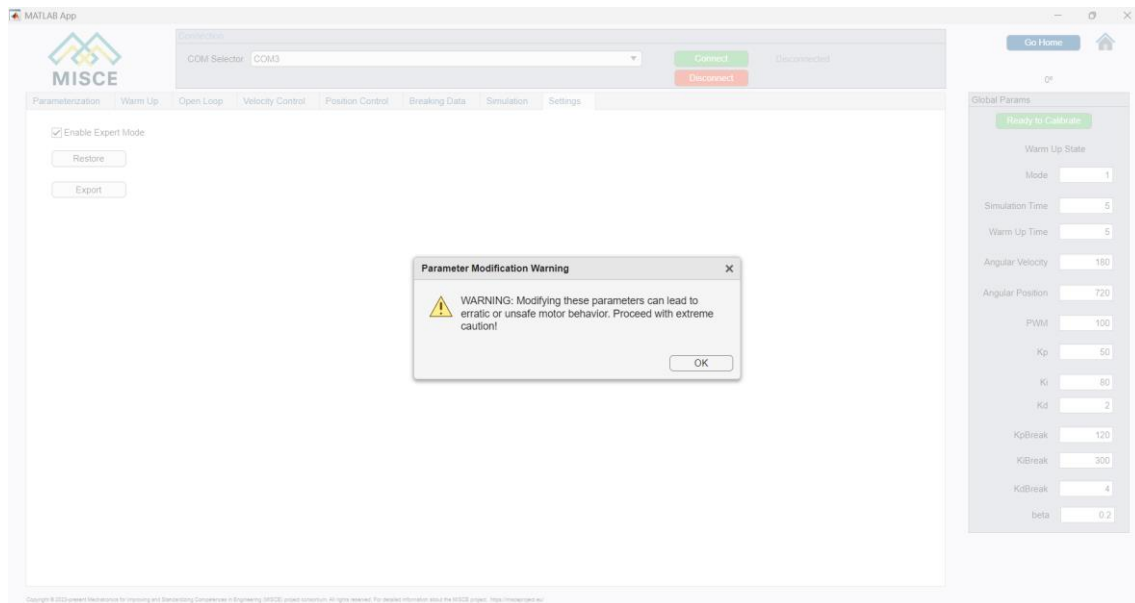


Figure 12. Warning message regarding setting parameters

At any time, the user can restore the default parameters by clicking the 'Restore' button.

Finally, all data generated, and parameters used can be export in two different ways by clicking the 'Export' button (see Figure 13):

1. To the Workspace in MATLAB for further processing of the data.
2. To a .mat file, which is a MATLAB type of file easily convert to excel, txt, or other commonly used formats.

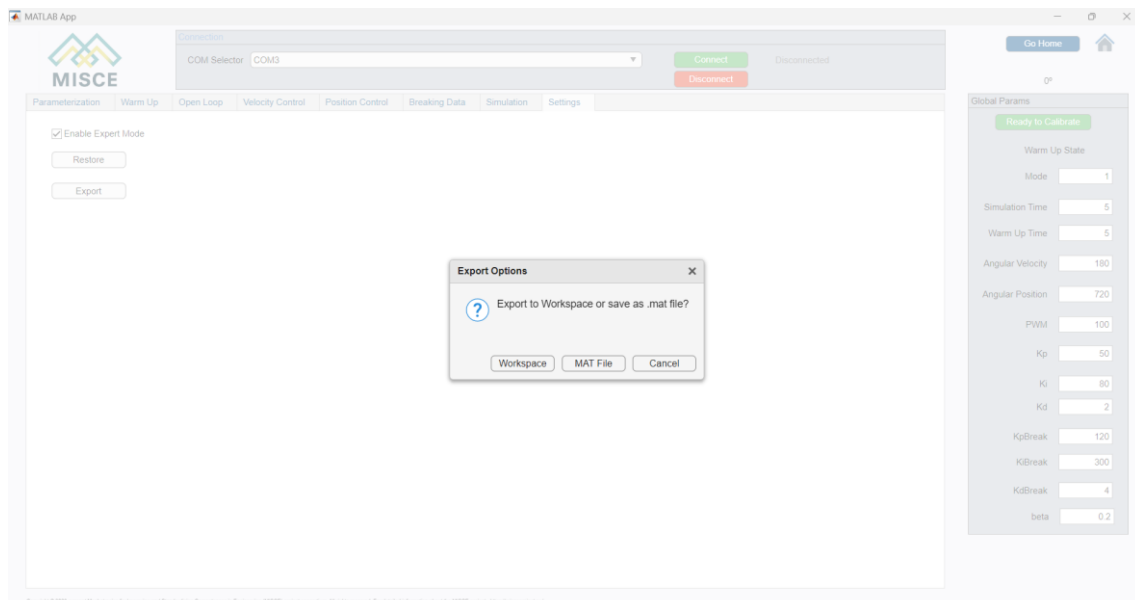


Figure 13. Type of export options for the recorded data



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- [1] Uicker, J. J., Uicker Jr, J. J., Pennock, G. R., & Shigley, J. E. (2023). Theory of machines and mechanisms. Cambridge University Press.
- [2] R. L. Norton, Mechanisms and Machine Theory. Pearson, 4th ed., 2009.
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