WheelMove-ID: User Manual

Privacy: For ethical reasons and thanks to the technical solution used (JavaScript), all calculations are performed solely on your computer. As a result, the data entered into the application is never transmitted to a server nor stored.

Table of contents

1. Introduction

This document is intended to enable informed use of the WheelMove-ID application, in accordance with the developers' original design and objectives.

The purpose of this application is to facilitate the identification of locomotor actions in manual wheelchairs (MWC) using inertial measurement units. Specifically, it allows the detection of stationary phases, forward and backward straight-line propulsion, as well as turning phases with different levels of curvature. Please note that, from a theoretical standpoint, the analysis is limited to motion on a flat horizontal surface. Although the application may operate on other surface types, transitions between different planes are not accounted for. Furthermore, this version does not identify slopes, camber (cross-slope), or other environmental obstacles.

The theoretical background of this approach is presented in a second manual, available in English via the "Help" tab of the application, as well as in the scientific articles associated with this work:

- Poulet, Y.; Brassart, F.; Simonetti, E.; Pillet, H.; Faupin, A.; Sauret, C. Analyzing Intra-Cycle Velocity Profile and Trunk Inclination during Wheelchair Racing Propulsion. Sensors 2023, 23, 58. https://doi.org/10.3390/s23010058
- Deves, M.; Sauret, C.; Alberca, I.; Honnorat, L.; Poulet, Y.; Hays, A.; Faupin, A. Activity Identification, Classification, and Representation of Wheelchair Sport Court Tasks: A Method Proposal. Methods Protoc. 2024, 7, 84. https://doi.org/10.3390/mps7050084

The application is based on the measurement of manual wheelchair (MWC) motion using inertial measurement units, following the protocol described below (see Experimental protocol using inertial measurement units). It operates in three main steps (Figure 1) :

- Data structuring
- Data preprocessing
- Task identification

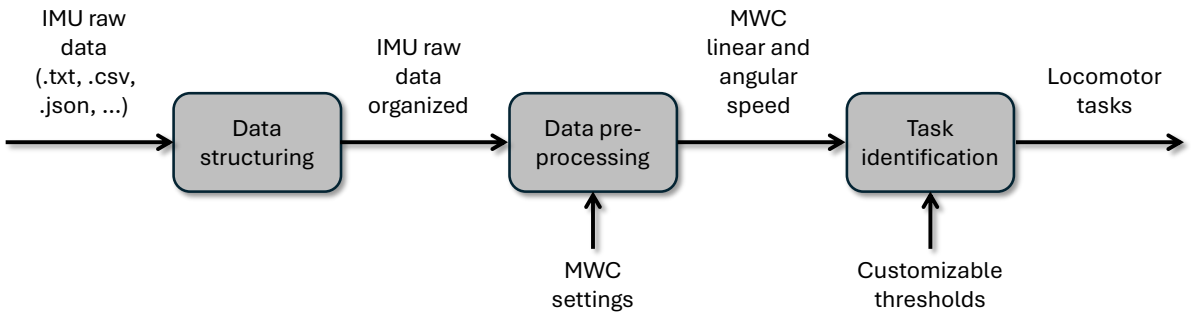

Figure 1: WheelMove-ID Operating Pipeline

Note: If measurement tools other than inertial measurement units are used to assess motion, the locomotor task identification step can be used independently of the first two steps.

2. Experimental protocol using inertial measurement units

2.1. Equipment

Three inertial measurement units and a measuring tape are required to perform the measurements. The inertial measurement units must be positioned on the manual wheelchair (MWC) as follows:

- Right and left rear wheels (1IMU each)
  - The sensor must be firmly attached, preferably at the wheel hub.
  - One measurement axis should be aligned as closely as possible with the wheel's axis of rotation.
- Frame (1 IMU)
  - IMU securely mounted under the seat on the chassis, as close as possible to the midpoint of the segment connecting the centers of the two rear wheels.
  - One measurement axis should be aligned as closely as possible with the anteroposterior direction of the MWC, within the sagittal mid-plane.

For the following steps, it will be necessary to know the wheel radius as well as their camber. A simple method for measuring the wheel radius is described in Section 4.2.

2.2. Calibration

Once the MWC is equipped with the three inertial measurement units, two calibration acquisitions must be performed:

- Static calibration
  - The static acquisition consists of recording data while the MWC remains completely stationary. It should last between 5 and 10 seconds. This acquisition is used to compensate for any misalignment of the inertial measurement unit mounted on the chassis. The user must be seated in the MWC in order to account for chassis deformation due to the load induced by the user's body weight.
- Straight-line calibration
  - The straight-line acquisition should preferably be performed with the user seated in the MWC. During this acquisition, an operator pushes the MWC in a straight line (following a ground line for greater accuracy) over a distance corresponding to more than two wheel revolutions. This acquisition is used to align the sensor reference frames with the rotation axes of the rear wheels.

Note: Calibration acquisitions must be repeated each time the position of any inertial measurement unit is modified, even slightly. If the sensors are not moved and the same MWC instrumented with the three inertial measurement units is used with another user, the static and straight-line calibrations may be reused. However, it is recommended to repeat them with the new user and to perform a new measurement of the wheel radius.

2.3. Data acquisition

Once the two calibration acquisitions have been completed, proceed with the measurement of the movements of interest.

Note: If possible, limit the acquisition duration in order to ensure a reasonable processing time.

Note: Any file containing missing data (or NaN values) will not be processed by the application.

3. Data structuring

The purpose of this first step is to gather the raw data from the inertial measurement units for each recorded movement into a single structured file, which will be used as input for the subsequent data preprocessing step. This approach makes it possible to extend the use of the application to a wide range of inertial measurement unit models.

3.1. Loading raw data files

As a first step, the files containing the raw data from the inertial measurement units must be loaded into the application. For improved compatibility, the following file formats are supported: .csv, .txt, .json, .tsv.

Note: WheelMove-ID does not support direct reading of manufacturer-specific file formats. Please use the data export functionality provided by the manufacturer's software to generate files compatible with the application.

Data from accelerometers are expressed in m/s^2. In order to accommodate the formats used by different inertial measurement unit manufacturers, data from gyroscopes may be provided in deg/s or rad/s.

3.2. Identification of relevant columns

In the **"First acquisition"** subsection of the page (Figure 2), use the drop-down menus to associate each inertial measurement unit with one of the previously loaded raw data files.

Note: If the raw data from the three inertial measurement units are contained in a single file, the file only needs to be loaded once and can be selected multiple times.

Once a file is selected, a correspondence table is displayed. This table shows the column headers of the raw data file as rows, and the data fields to be identified for further processing as columns.

Next, associate each row with the corresponding data field by selecting the appropriate checkboxes (Figure 2).

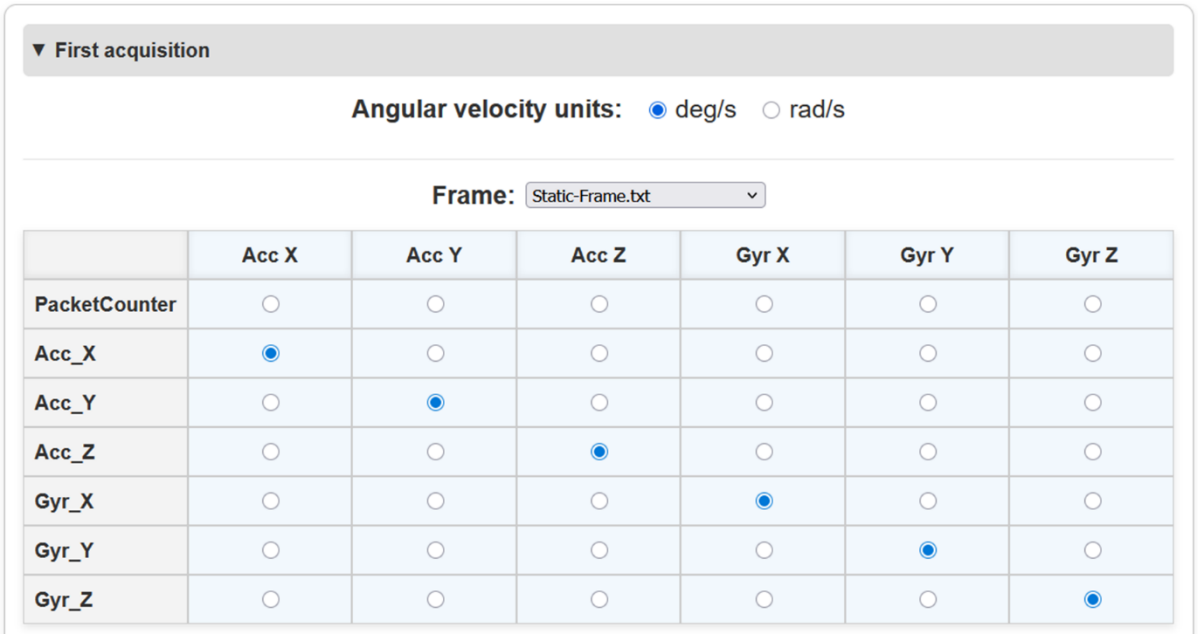

Figure 2: Correspondence table for the frame IMU.

3.3. Batch processing

Batch processing allows the previously defined column correspondence to be applied to a large number of files. To do so, use the drop-down menus in the table (Figure 3) to specify the file associated with each inertial measurement unit for each acquisition. Use the first column, "**Acquisition name**", to name each acquisition.

The two buttons located below the table allow you to add or remove a row from the table.

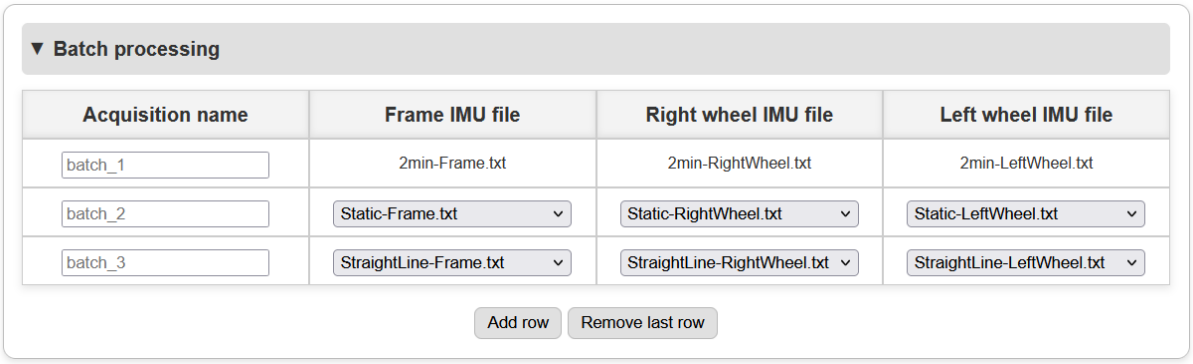

Figure 3: Batch processing example with sample data.

3.4. Footer buttons

3.4.1. New acquisition(s)

This button reloads the page.

Note: It is only useful when changing the brand or model of inertial measurement units between acquisitions. Otherwise, the use of the "Batch processing" option is recommended.

3.4.2. Generate CSV file(s)

This button downloads a compressed folder named “imu_batch_export.zip” to the **“.../Downloads”** directory. The folder contains the .csv files corresponding to the acquisitions. Each generated file includes 18 columns representing the accelerometer and gyroscope data from each inertial measurement unit (chassis, right wheel, and left wheel).

3.4.3. Data preprocessing

This button provides access to the data preprocessing page (see Section 4.Data preprocessing)

4. Data preprocessing

Data preprocessing is carried out in five steps, described below. For each step, the user must enter the required data and then click the **"Validate"** button to proceed to the next step. After the first validation, the **"Edit"** button becomes active, allowing values to be modified.

If the **"Validate"** button is greyed out and inaccessible, this indicates that some data are missing in the current step.

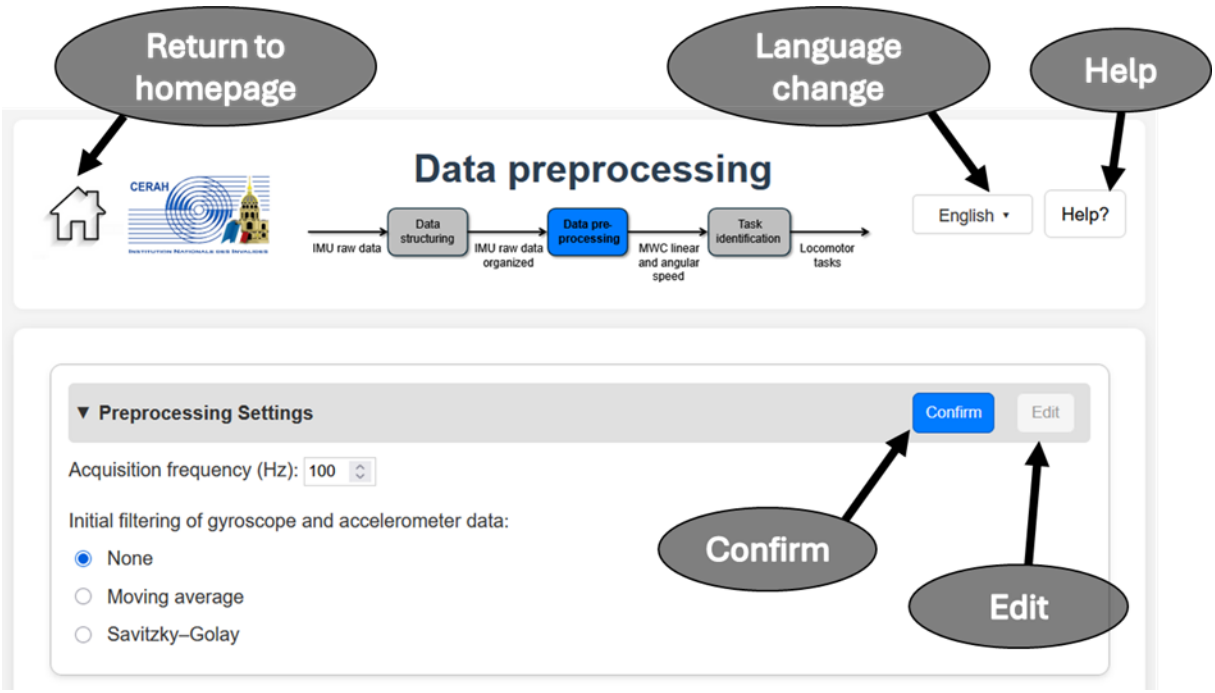

Figure 4: Interface overview

4.1. Preprocessing parameters

Enter the **acquisition frequency** (in Hz) of the inertial measurement units. The acquisition frequency must be the same for all units and for all acquisitions to be processed.

Select the filter to apply to the raw gyroscope and accelerometer data:

- **None**: Raw data are not filtered.
- **Moving average**: Applies a centered moving average with linear extrapolation to limit edge effects. The processing is applied in both directions to minimize phase shift. The window size can be set by the user. Note: The window size must be an odd number.
- **Savitzky-Golay**: Applies the Savitzky–Golay algorithm to smooth the data. The user must specify the processing window (odd number) and the order of the polynomial used.

  Note: the window size must be at least equal to the polynomial order + 1 (for example, at least 3 values for a second-order polynomial, 5 values for third- and fourth-order polynomials, 7 values for a fifth-order polynomial, etc.).

4.2. MWC parameters

- **Camber** Refers to the inclination angle of the MWC wheels relative to the vertical.

- **Rear wheel radius/circumference**: The user can choose to enter either the radius or the circumference of the rear wheels by toggling the button. The highlighted word indicates the selected option. Values must be entered in centimeters. For more precise analysis, the user can specify different measurements for the left and right wheels by clicking the **"Differentiate left/right"** button.

Note: It is recommended to measure the circumference and differentiate the wheels. The circumference can be determined by the distance traveled by the wheel in a straight line for a full rotation, using, for example, a valve positioned vertically on the ground as a reference.

- **Rear track (cm)**: Enter the distance between the contact points of the two rear wheels with the ground, in centimeters. Combined with the camber angle, this measurement allows the automatic calculation of the distance between the centers of the rear wheels.

4.3. Static acquisition

Use the button or drag-and-drop area to load a static acquisition (see Calibration).

If the wrong acquisition is loaded, it can be deleted by clicking the red cross in the **"Action"** column of the corresponding table.

4.4. Straight-line acquisition

Use the button or drag-and-drop area to load a straight-line acquisition (see Calibration).

If the wrong acquisition is loaded, it can be deleted by clicking the red cross in the **"Action"** column of the corresponding table.

4.5. Acquisitions to process

Use the button or drag-and-drop area to load the acquisitions to be processed.

Note: The inertial measurement units must not be moved at any time between the calibration acquisitions and the acquisitions to be processed.

Loaded acquisitions can be deleted by clicking the red cross in the **"Action"** column of the corresponding table.

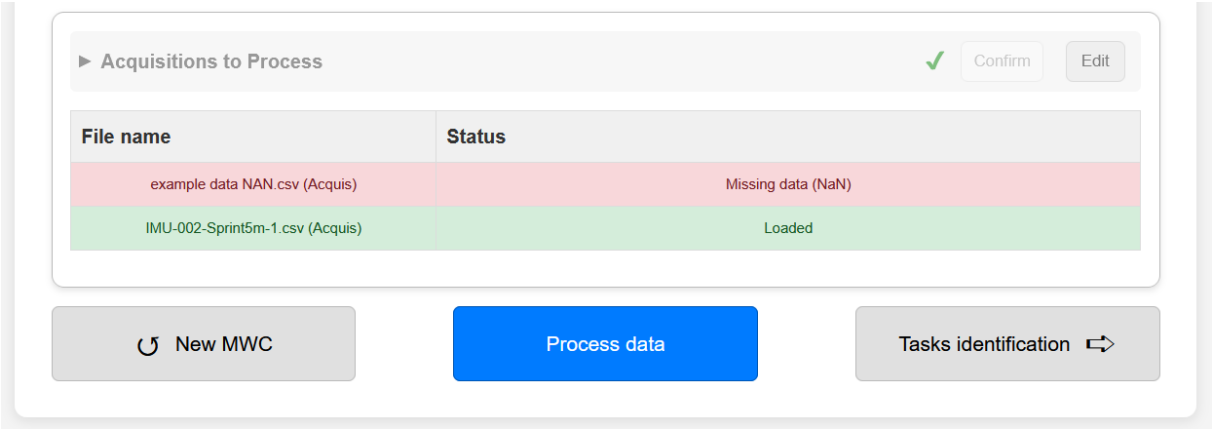

Figure 5: Example of loading a file with missing data (red row) and a functional file (green row)

Validation of this step activates the footer button **“Process data”.**

4.6. Footer buttons

4.6.1. New MWC

Allows returning to Step 4.2 to enter the data of a new MWC to be processed.

This button should be used after saving the results of one MWC in order to preprocess another MWC while keeping the preprocessing parameters entered in Section 4.1.

4.6.2. Process data

Performs the preprocessing of the loaded acquisitions.

Downloads one .csv file per acquisition to the **“.../Downloads”** folder. The files, named ..._preprocessing.csv, contain three columns:

- Time (s): Temporal signal indicating the progression of time during the acquisition.
- Linear velocity (m/s): Movement speed along the MWC’s anteroposterior axis.
- Angular velocity (deg/s): Angular velocity of the MWC, i.e., its rotational speed around the vertical axis.

4.6.3. Task identification

Provides access to the locomotor task identification page (see Section 5.Identification of locomotor tasks).

5. Identification of locomotor tasks

This page is designed to identify locomotor actions based on the linear and angular velocities of the MWC.

The identification of locomotor actions is carried out in four main steps:

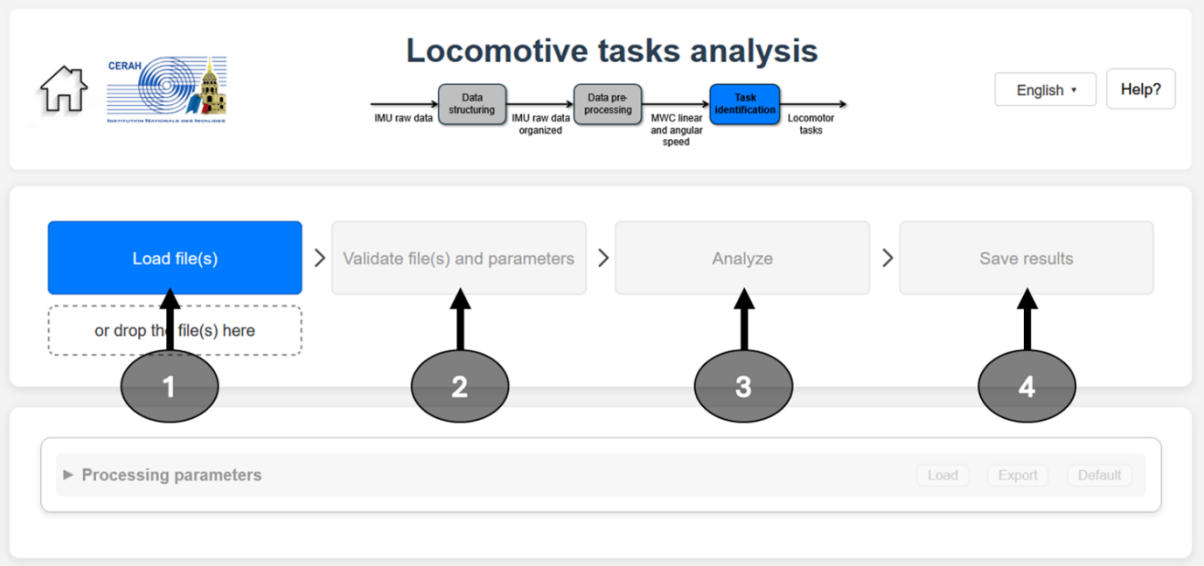

Figure 6: Steps for locomotor task identification

5.1. Loading data

Use the button or drag-and-drop area to load the preprocessed files for analysis. Files generated from the previous page can be loaded as they are. Multiple files can be loaded simultaneously.

Note: When these velocities are obtained using sensors other than inertial measurement units, the WheelMove-ID application can be used directly from this step. In this case, it is essential to ensure that, at each time point, the linear and angular velocities are expressed in the MWC reference frame. In this frame, the linear velocity must be projected only along the anteroposterior axis, and the angular velocity along the vertical axis. The files must be provided in .csv format and contain at least two columns with headers:

- The first column must contain the MWC linear velocity in (m/s) and its header must include the string "lin" for "linear velocity."
- The second column must contain the MWC angular velocity in (°/s) and its header must include the string "ang" for "angular velocity."

5.2. Validate files and parameters

This button locks the loaded files, which are displayed in the table at the top of the page, along with the processing parameters.

Before clicking this button, the **acquisition frequency** and the **threshold** values used in the analysis can be customized. Each threshold corresponds to the value at which the algorithm considers transitions between **States 1, 2, and 3**, as specified in the table.

New linear and angular velocity thresholds, specified below the table, allow, after an initial identification of locomotor actions, a more precise determination of the exact transition times between states through additional processing.

See the theoretical manual in English, available in the application's Help section, for more details on the calculations performed and the use of each threshold.

The **"Load"** and **"Export"** buttons allow exporting the processing parameter values to a .json file, which can later be loaded to quickly perform the same analysis on different acquisitions.

The **"Default"** button resets the thresholds and frequency to their default values.

5.3. Analyze

The **"Analyze"** button starts the identification of locomotor actions on the previously loaded files using the specified parameters.

This results in the display of chronograms, their legend at the bottom of the page, and two checkboxes allowing the visualization of linear and angular velocities on the chronograms.

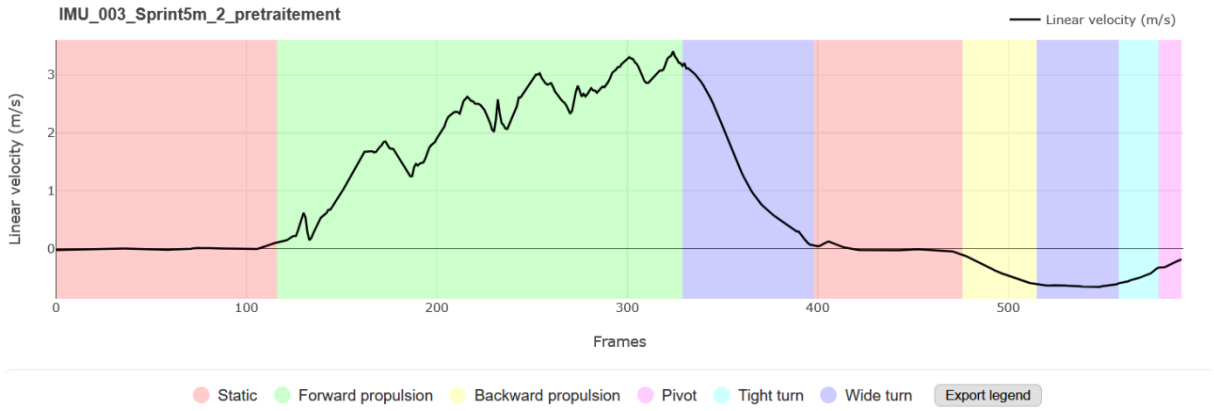

Figure 7: Example of a chronogram obtained from data analysis.

5.4. Save

5.4.1. Save results

The **"Save"** button downloads one .csv file per loaded acquisition to the **"…/Downloads"** folder. The files, named …_result.csv, contain four columns:

- Time (s): Temporal signal indicating the progression of time during the acquisition.
- Linear velocity (m/s): Movement speed along the MWC's anteroposterior axis.
- Angular velocity (deg/s): Angular velocity of the MWC, i.e., its rotational speed around the vertical axis.
- Locomotor actions: A number from 1 to 6 representing the six actions identified by the application, according to the legend:
    - 1: Stationary
    - 2: Forward propulsion
    - 3: Backward propulsion

- 4: Pivot
- 5: Sharp turn
- 6: Wide turn

5.4.2. Export legend

The **“Export legend”** button, located at the bottom right of the legend, allows exporting the legend.

6. Sample data

A sample dataset is available for download directly from the “**Help”** section to help users become familiar with the application.

7. Contact us

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