

STAGAMOD – ND

Documentation

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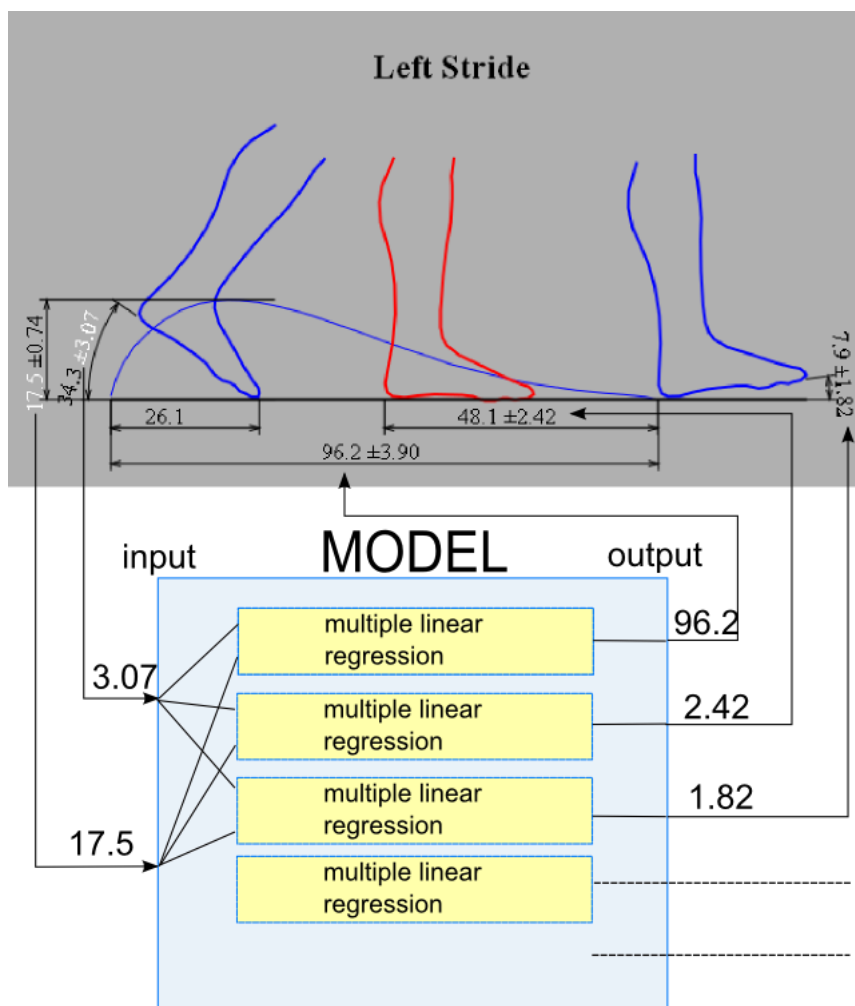
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2 Introduction

StaGaMod – ND is an interactive tool for the visualization of dependencies between different gait-parameters of subjects with various neurological diseases. Multiple linear regressions are used to calculate the expected values (output values) from a set of independent values (input values). Both types of values are shown in the same dynamically build technical drawing where input values are written in white and output values are in black letters.



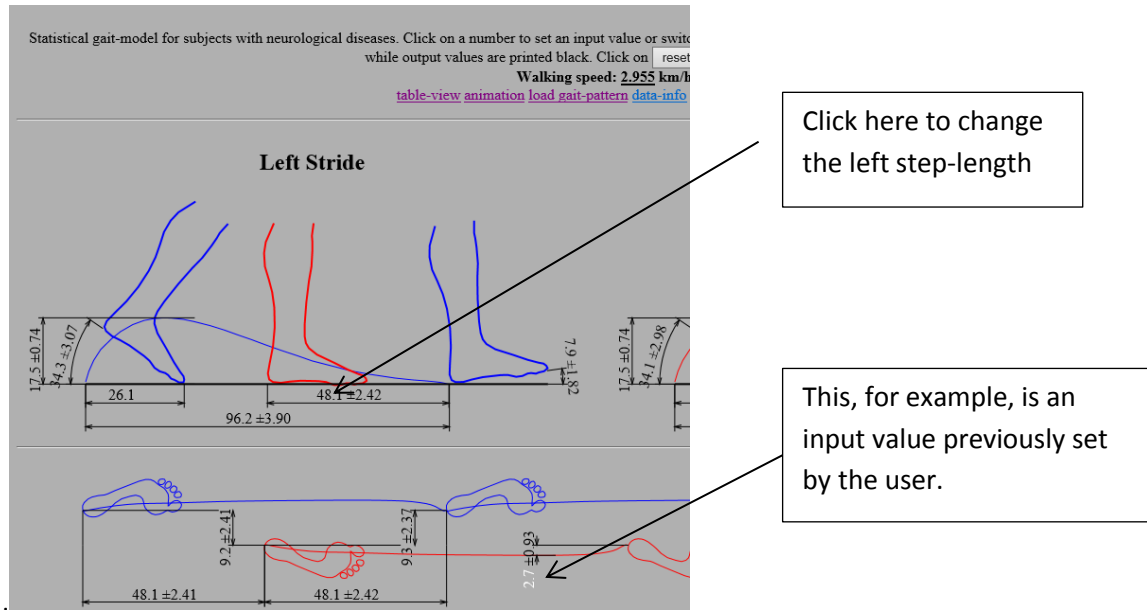
The upper part of this figure shows a part of the user surface of StaGaMod – ND (i.e. a part of the technical drawing mentioned above) while the lower part of the figure shows how the calculation in the background works.

3 Usage

StaGaMod – ND must always be entered at the page [graphic-view](#) to work correctly. Cookies must be enabled by the browser. They are solely used to store the selected input values of the model. The browser must support inline SVG and [X3DOM](#) for the visualization of the graphics and the 3-d animation respectively.

3.1 Set Input Values

After startup or pressing the “reset model” button mean values of all parameters are shown. One may click on a number to make that specific parameter an input value. Example:



The window of the parameter „step_length_left_mean“ then opens:

http://nrz-therap.nrz.local/StatisticalGaitModel/messwert.php?name=VL_step_length_left_m

nrz-therap.nrz.local

Output-Parameter: **step_length_left_mean**

Value: 48.0982

set value (make the parameter an input-parameter)

reset value (make the parameter an output-parameter)

reset model (set all parameters as output)

[Back to graphic-view](#) (change nothing)

[Switch to table-view](#) (change nothing)

$r = 0.062$

Name of the parameter. Printed black if it is an output parameter, white if it is an input parameter.

This field shows the maximum likelihood-value as long as the parameter is an output parameter. It can be changed by typing a new value.

Click here to make the parameter an input parameter.

3.2 Parameter Limits

In order to give the user a maximum of freedom there are no range checks of the input values. Warnings are listed in the column “deviation from average” of the table view if input- or output-parameters are out of range.

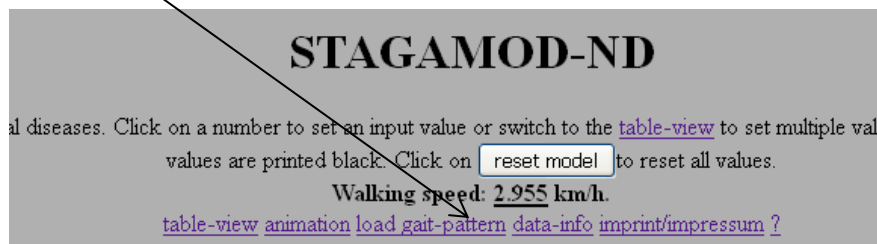
Example:

Parameter	Minimum	Maximum	Input_Value	Unit	Set_Default	Reset	Expected_Value	Deviation_from_Average
Speed	0.36456	6.26386	<input type="text" value="set values"/>	km/h	<input type="radio"/>		0.16975771086	out of range -2.79
stride length left mean	23.0573	165.154	<input type="text"/>	cm	<input type="radio"/>		31.2143134439	-64.95
stride length right mean	23.3001	171.938	<input type="text" value="22"/>	cm	<input type="radio"/>	<input type="radio"/>		out of range -74.08
step length left mean	4.34134	91.4942	<input type="text"/>	cm	<input type="radio"/>		-17.7822138893	out of range -65.88

However, the graphic-view or the animation may look confusing if extreme values are entered but a click on the button “reset model” should always solve the problem.

3.3 Loading Gait Patterns

Average values of individuals with distinct neurological diseases can be loaded by a click on the link [load gait-patterns](#) in the head of the graphic-form.



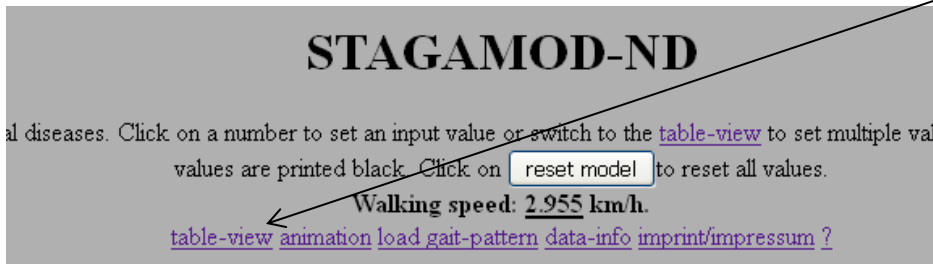
Unfortunately, some browsers are limited to 50 cookies and therefore only 50 input-parameters can be defined simultaneously. In that case, one may prefer to load the parameter set without the standard deviations.

3.4 Animation

The link [animation](#) in the head of the graphic-form starts a 3-d animation of the gait pattern defined by the actual parameters of the model. The scene can be rotated by shifting the mouse within the frame while the left mouse-button is pressed. Considering rotating a sphere by touching it on the front might help to understand the effect.

3.5 The Table View

The table-view is an alternative to the graphic-view. It can be entered by a click on the link [table-view](#) in the head.



Columns of the table-view:

Column	Meaning
Parameter	Name of the gait parameter
Minimum	Minimum of the measured sample
Maximum	Maximum of the measured sample
Input_value	Field to enter an input-value. The parameter is an output-parameter if this field is empty.
unit	Unit of the parameter
Set_default	If this button is marked, the parameter will be initialized with the mean value and set as an input-parameter when the button "set value" is pressed.
reset	If this button is marked, the parameter will be set as an output-parameter if "set value" is pressed.
Expected_value	The value calculated by the model.
Deviation_from_Average	Difference of the expected value and the average. The latter is the expected value after pressing "reset model".

Be aware that changes are only recognized if the button "set values" is pressed.

4 Background Information

4.1 Data Acquisition

All data has been recorded at the gait laboratory of the neurological rehabilitation center NRZ-Rosenhügel, Rosenhügelstraße 192a, 1130 Vienna, Austria. Actual parameters of the recorded sample can be found in the section [data-info](#).

4.1.1 Gait-Laboratory

The following picture shows the gait-laboratory at the NRZ-Rosenhügel:



At the top from about from the middle to the left one can see 3 of the 6 Vicon cameras mounted on the wall or the ceiling. The walkway is marked with black tape on the floor. Two AMTI force measurement platforms can be seen in the middle of the walkway but they are not applied in that specific measurement procedure.

4.1.2 Walkway

The complete length of the fixed floor walkway is 7.8 m. However, to achieve a stable gait pattern and to guarantee good views from the cameras the section where the recorded data is actually used is 3.5 m long and located at about the middle of the complete walkway.

4.1.3 Equipment

Data acquisition was performed with the optical motion tracking system Vicon 460 using 6 infrared high speed cameras (type MCam) at a sample frequency of 120Hz.



Vicon MCam with circular infrared spot.

4.1.4 Marker Placement

There are two spherical retroreflective markers with 14mm diameter fixed on each foot: one on the heel at the distal end of the achilles tendon (tendo calcaneus), the second on the forefoot half the way between the inner and the outer edge.



4.1.5 Trial Conditions

After the application of the markers the subjects are instructed to walk the marked walkway up and down on their usual speed. If possible, the patient walks barefoot without a walking aid. Nevertheless, if necessary walking aids or footwear can be used, too.

Recording is started by the operator and normally stops after 90 seconds. Afterwards, the software splits the recorded data into subtrials each time the subject changes the walking direction.

4.1.6 Software

Vicon Workstation is used for the reconstruction of the 3d traces of the markers. Due to the long period of time of the data acquisition several versions of the program (starting with V4.4 in year 2002) have been used.

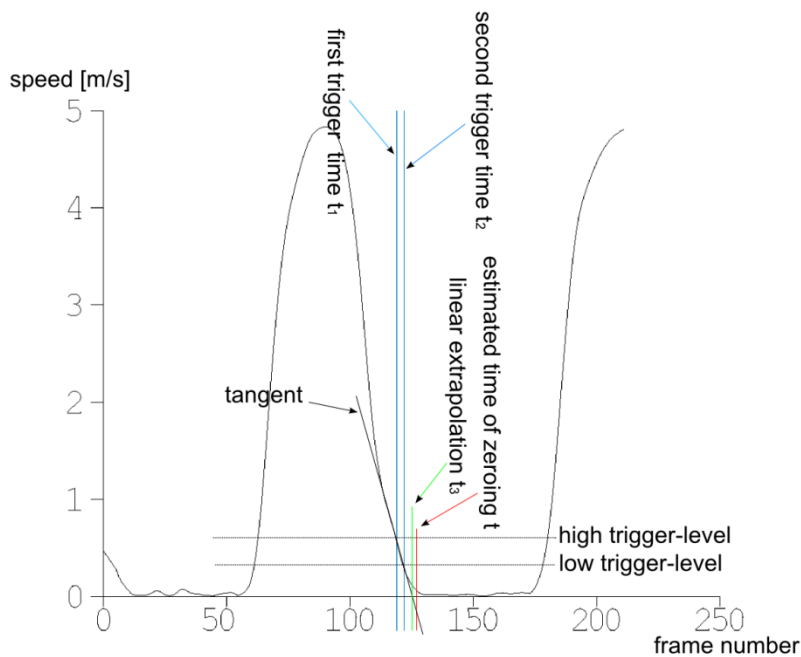
Further processing of the raw data to final gait parameters is performed by the [Videometrie Schnelltest](#). This procedure is part of the [Motion Analysis Language](#) software system.

4.2 Data Preparation

4.2.1 Calculation of Instants

The force platforms have not been applied in the measurement procedure because most of the patients are not able to hit them correctly. Timing parameters like “heel down” or “toe up” are therefore calculated from the marker movement or more precisely: the marker speeds. For example: the instant of “heel down” is when the heel-marker slows down to zero speed. Two dynamic calculated trigger levels and an extrapolation algorithm are used to estimate the exact instant.

The following figure shows the speed of the forefoot-marker and the corresponding calculation of the “toe down” instant.



The trigger levels are set by the signals average as follows:

$$h = 0.5 * \text{mean}(\text{speed})$$

$$l = 0.25 * \text{mean}(\text{speed})$$

h ... high trigger-level

l ...low trigger-level

Assuming linear extrapolation the intersection of the tangent and the zero-line would be at

$$t_3 = t_2 + (t_2 - t_1)$$

t_1 ... first trigger time

t_2 ... second trigger time

t_3 ... intersection of the tangent and the zero-line

However, the speed normally does not meet the zero-line where the tangent does. A constant correction factor f is therefore recommended. The complete calculation of the estimated time of zeroing looks as follows:

$$t = t_2 + f * (t_2 - t_1)$$

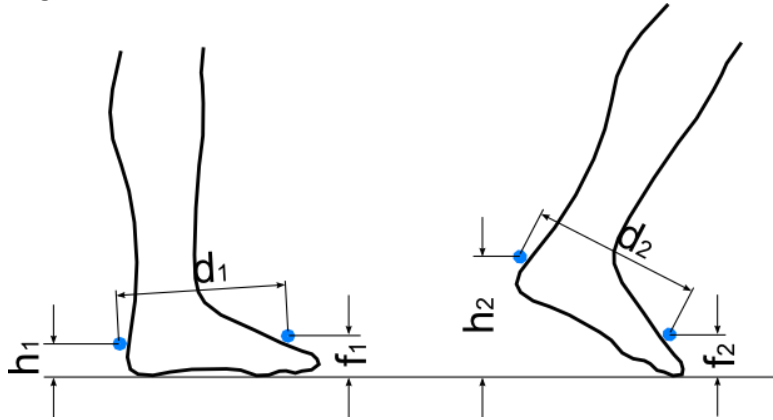
t ... estimated time of zeroing

The following table shows the used parameters for the calculations of all time landmarks:

Instant	Marker	Trigger-Slope	f
Heel-Down	Heel	-	-0.7
Toe-Down	Toe	-	0.3
Heel-Up	Heel	+	0.8
Toe-Up	Toe	+	-2.3

4.2.2 Calculation of Angles

The parameters “lift angle” and “lower angle” are calculated by building the difference of two 2-d angles as follows:



Calculation:

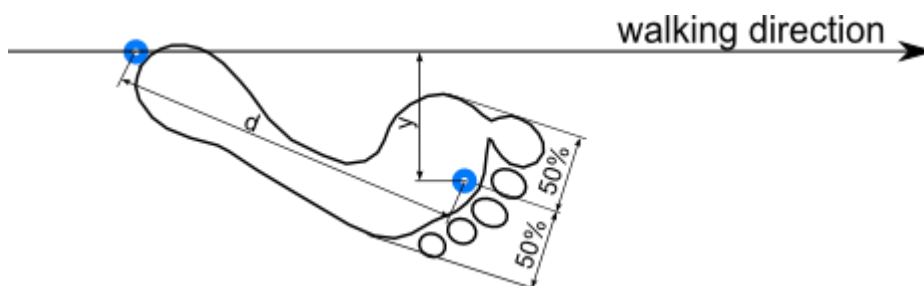
$$\alpha_1 = \arcsin((h_1 - f_1) / d_1)$$

$$\alpha_2 = \arcsin((h_2 - f_2) / d_2)$$

$$\alpha = \alpha_2 - \alpha_1$$

- h_1 ... Distance from the floor to the heel-marker at stance phase
- f_1 ... Distance from the floor to the forefoot-marker at stance phase
- d_1 ... Distance between the two markers at stance phase
- h_2 ... Distance from the floor to the heel-marker at toe-off instant
- f_2 ... Distance from the floor to the forefoot-marker at toe-off instant
- d_2 ... Distance between the two markers at toe-off instant
- α_1 ... Angle at stance phase
- α_2 ... Angle at toe-off instant
- α ... lift angle

The parameter “outward rotation” is calculated as the angle between the straight line between the two foot-markers and the walking direction or more exactly: the x co-ordinate of the measurement system.



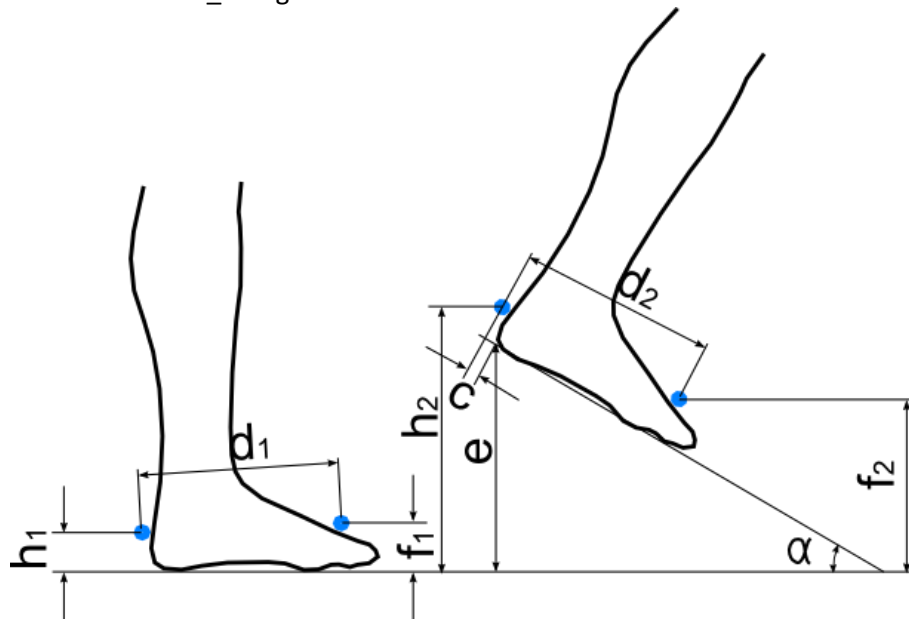
Calculation:

$$\alpha = \arcsin(y/d)$$

- d ... Distance between the two markers
- y ... Difference of the y co-ordinates
- α ... outward rotation

4.2.3 Calculation of Distances

1. Parameter "heel_lifting":



The parameter "heel_lifting" represents the maximum of the vertical position e of the heel where e is calculated as follows:

$$\begin{aligned}\alpha_1 &= \arcsin((h_1 - f_1) / d_1) \\ \alpha_2 &= \arcsin((h_2 - f_2) / d_2) \\ \alpha &= \alpha_2 - \alpha_1 \\ e &= h_2 - h_1 * \cos(\alpha) - c * \sin(\alpha)\end{aligned}$$

c ... constant = 8mm

2. The parameters "step_length" and "stride_length" are the movement of the heel-marker in walking direction (or more precisely the x co-ordinate) from one step to the next or one stride to the next respectively.
3. The parameter "step_width" is the y co-ordinate of the movement of the heel-marker from one step to the next.
4. The parameter "foot_length" f is an estimate based on the distance d between both markers and is calculated by the function $f = (d - 10\text{mm}) * 1.38$

4.2.4 Standard Deviations

Parameters labeled "..._stddev" are standard deviations of all steps within one session. The lower a standard deviation the higher is the repetition precision of the steps. One may say, "the gait pattern is more stable" then.

4.2.5 Averaging

Normally, at the NRZ-Rosenhügel gait measurements are performed at the beginning and at the end of a rehabilitation period (most often 30 days). Some people were recorded more often (if they consumed more periods of rehabilitation) and some less (for different reasons). Anyway, the model only takes average values of all sessions for a specific patient.

4.3 The Model

The statistical model is based on multiple linear regressions where certain parameters are transformed to achieve normal distribution.

Table of transformations:

Type of value	Input transformation	Output transformation
Standard deviation	$x_i = \log_{10}(x_t)$	$x_t = 10^{x_o}$
Time value if not a standard deviation	$x_i = 1/x_t$	$x_t = 1/x_o$
Others	none	none

x_t ... true value

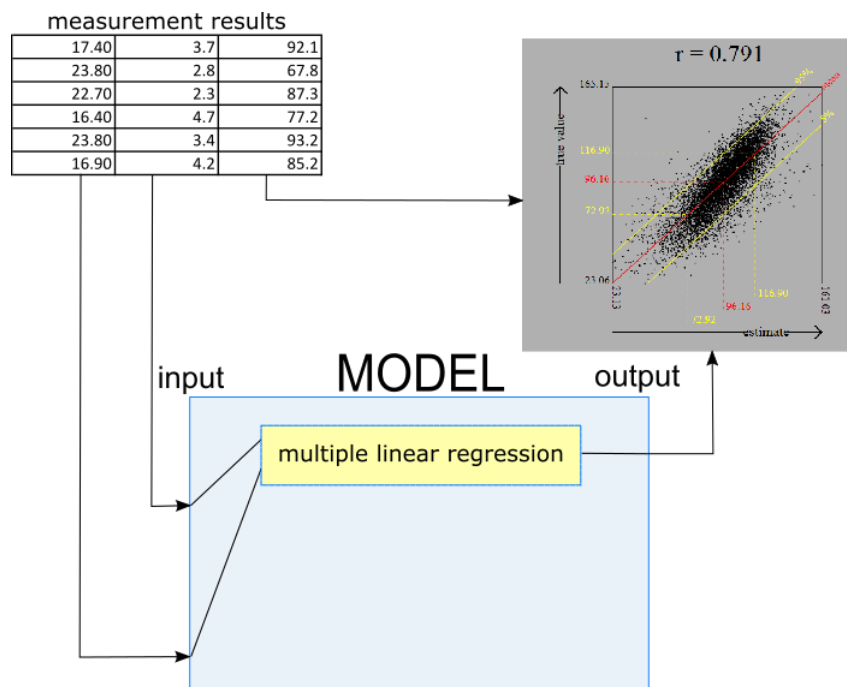
x_i ... input to the regression

x_o ... output of the regression

Averages of the sample data are shown if all parameter are set as output values (for example after “reset model”). If one value is set as an input value the others are estimated by simple linear regressions while multiple linear regressions are applied if there are two or more input parameters.

4.4 Regression-Plot of Estimates

A click on a value causes a change to the value input/output frame. If the value is an output parameter and at least one other parameter is set as an input, a plot of a linear regression with the model output as independent value (x co-ordinate) and the true measured value as independent value is shown. The scaling of this plot depends on the input/output transformation (see table above). However, the written numbers are always true values.



The yellow lines are parallel to the regression line and limit a range where 90% of the sample can be found. Be aware that this is not exactly the range of confidence for the prediction.

The exact range of confidence of the prediction shown in the table labeled “Range of Confidence” uses the following formula:

$$\hat{y}_p \pm t_{\alpha/2, n-(k+1)} \sqrt{\hat{\sigma}^2 (1 + x_p' (X'X)^{-1} x_p)}$$

Refer to http://reliawiki.org/index.php/Multiple_Linear_Regression_Analysis concerning the meaning of the parameters.

4.5 Animation

The animation is based on averaged time-rows. One must be aware, that only certain key-frames are defined by the models input/output parameters. Everything between those key frames is up to interpolation and therefore more or less a question of design. Furthermore, not all parameters are used for the calculation. Specifically, none of the standard deviations are taken into account. Instead of the parameters `stride_length_left_mean` and `stride_length_right_mean` the sum of `step_length_left_mean` and `step_length_right_mean` is used.

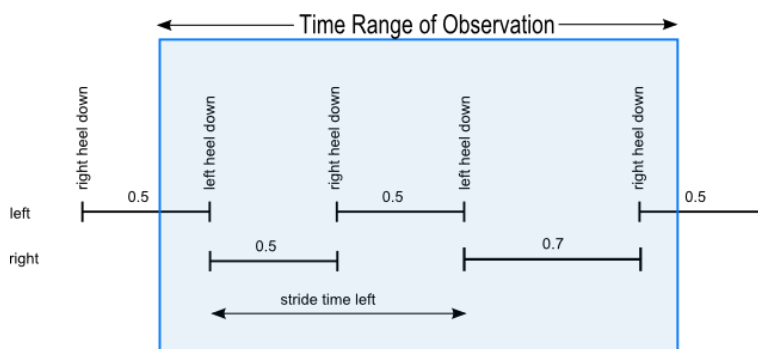
4.6 Considerations Concerning Precision

Obviously, there are some output values of the model not exact. For example: from a logical point of view the sum of the parameters “`step_time_right`” and “`step_time_left`” should always be exactly the same value as “`stride_time_left`” or “`stride_time_right`”. Another example: if the parameter “`lower_angle`” is set to zero both “`heel-contact`” and “`toe-contact`” should start at the same instant.

The lack of precision of the model maybe caused by three different reasons:

1. Statistical Reason

In theory, statistic is an exact science but only for an infinite sample. Considering the following realistic situation of data acquisition one may understand why the sum of “`step_time_left`” and “`step_time_right`” not always equals the “`stride_time`”:



The mean value of the step-time-right is $(0.5 + 0.7) / 2 = 0.6$ and the mean value of step-time-left is 0.5 while the measured stride-time-left is 1.0.

2. Limits of the Linear Model

The linear model assumes that any dependency of a parameter \bar{y} from some others is exactly defined by an equation like this:

$$\bar{y} = c_0 + c_1 * x_1 + c_2 * x_2 + c_3 * x_3 \dots$$

Where c_i are constants and x_i the independent values. Indeed, in gait analysis only a few dependencies will meet this condition exactly.

3. Measurement Errors

StaGaMod-ND is based on measurements and measurement errors can disturb the results of

the model. Normally, optical motion recording systems like the Vicon-System are very precise concerning distance-parameters and angles. Timing parameters, however, cannot be recognized very exactly. This is not caused by a lack of precision of the equipment but rather by the difficulties of the recognition of instants when the floor is hit or left.

Furthermore, in some seldom cases the measurement results may be completely wrong. Usually, the results are then called "outliers". Motion measuring is a complex task and outliers can be caused by several reasons (hidden markers, ghost-markers, wrong step recognition etc.). The software performs some plausibility checks to suppress outliers but, however, they cannot be completely avoided.