



Съфинансирано от
Европейския съюз



ПРОГРАМА
КОНКУРЕНТОСПОСОБНОСТ И
ИНОВАЦИИ В ПРЕДПРИЯТИЯТА

Modeling of Lifting Systems in Waste Collection

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Reference :

[1] D. Knežević and V. Savić,
"Mathematical Modeling of Changing of Dynamic Viscosity
, as a Function of Temperature and Pressure
, of Mineral Oils for Hydraulic Systems,"
Facta Universitatis, Series: Mechanical Engineering
, vol. 4, no. 1, pp. 27-34, 2006.



Modeling of Lifting Systems in Waste Collection

This presentation considers the problem of estimating the mass of waste emptied from individual containers by a garbage truck equipped with standard lifting forks for both large 1100-liter containers and smaller waste bins.

The main objective is to develop a low-cost measurement system that can be applied to a wide range of truck configurations with only minimal hardware modification.

The system combines an oil pressure sensor installed in the hydraulic circuit and a standard smartphone inertial measurement unit fixed on the lifting arm.

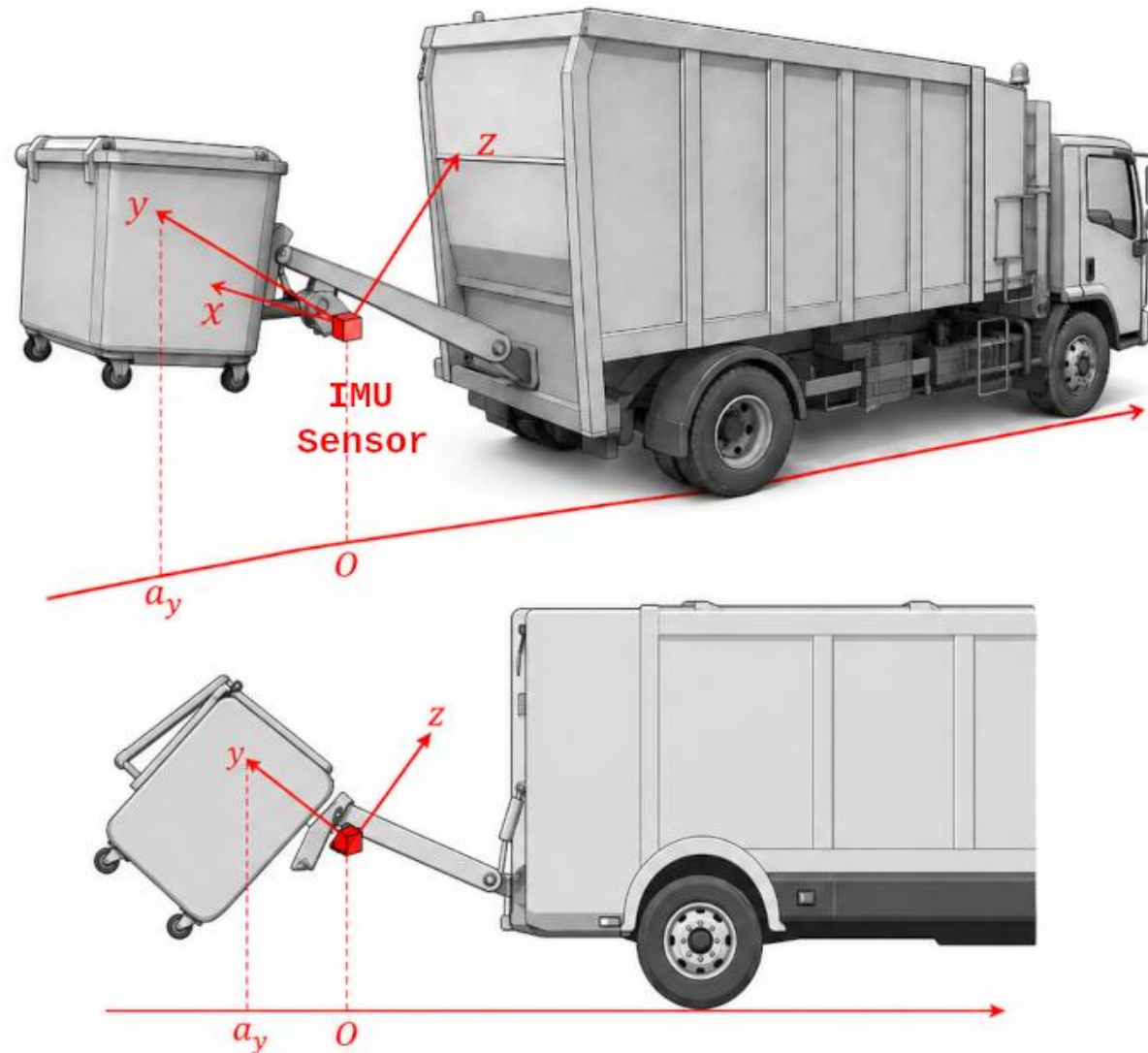
The pressure sensor provides a measure for determining the lifting force, while the accelerometer and gyroscope are used to estimate the motion of the lifting arm.

From these measurements and a calibrated model, the dumped waste is determined.

The main focus of the presentation is the physical and mathematical structure of the method.



IMU Sensor Coodinate System





Raw Data

Example CSV data file content :

```
ax, ay, az, gx, gy, gz, adc, adc2  
311, 15150, -5460, -110, -11, 10, 124477, 126303  
519, 15484, -6729, -154, 52, 17, 124478, 126314  
1033, 15285, -6283, -94, 15, 11, 124470, 126282  
441, 15182, -5413, -105, -9, 10, 124473, 126333  
417, 15551, -6758, -139, 42, 9, 124434, 126340  
1007, 15304, -6345, -96, 24, 17, 124479, 126319  
456, 15128, -5402, -92, -12, 7, 124449, 126297  
373, 15464, -6555, -131, 32, 17, 124449, 126255  
...
```

ax(t) is accleration on the axis x

gx(t) is rotation speed around axis x, measured from the gyroscope

adc(t) is lift pressure measured from pressure sensor

adc2(t) is pressure on drop hydraulic cycle from a second sensor

Each data row is all samples measured with 10 ms time step



Rotation Angle

Find **static intervals** - time intervals with no physical rotation

max_gyro_value when no real rotation
min_duration considered valid interval
damp_time enough for decay of any entering vibration
lag_time max time for a gyro signal to exit the limit

Remove **gyro** drift.

Orientate **axis x** to match the rotation axis.

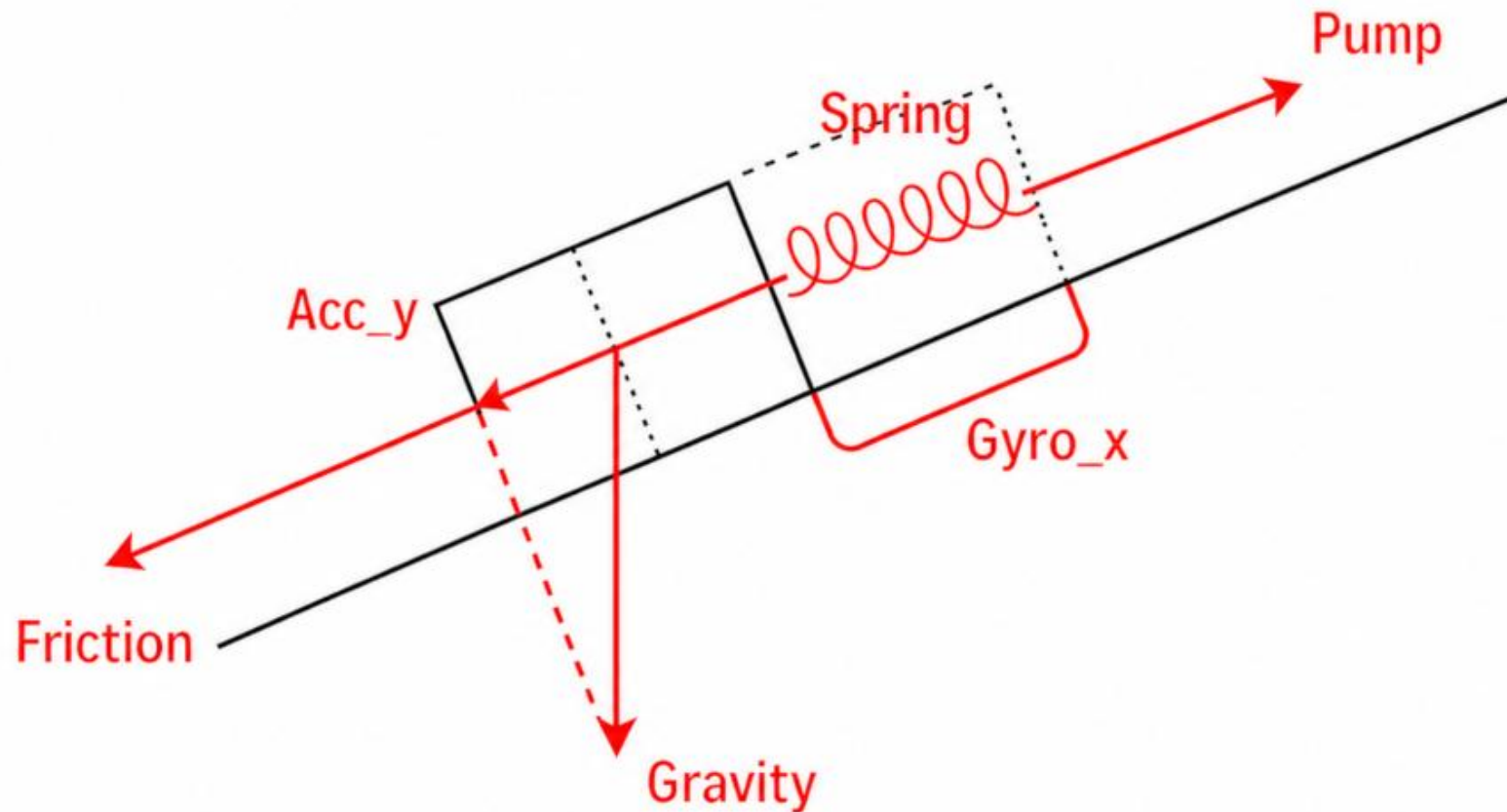
Not constant during the whole dump movement.
For choosing rotation axis
, hand select an interval from the plot.

Calculate **angles**, integragring **gyro ax** values

Summation of many small float values.



Physics



$$\text{Work} = \text{Force} * \text{Distance}$$

$$\text{Pump_work} = \text{Friction_work} + \text{Gravity_work} + \text{Viscosity_work}$$



Setup Parameters

Valid_angles

Determined from calibration data.

`min_valid_angle` tallest container is lifted
`max_valid_angle` trash do not move significantly

Orient_mov_angle

Rotation angle around `axis x`, such that
the move direction of the geometric center
of the whole moving assembly
is parallel to `axis y`.

Smooth_time

For removing the vibrating spring effect.



Forces

Friction_force ~=
Gravity_force ~=
Viscosity_force ~=
Pump_force ~=
 Pressure

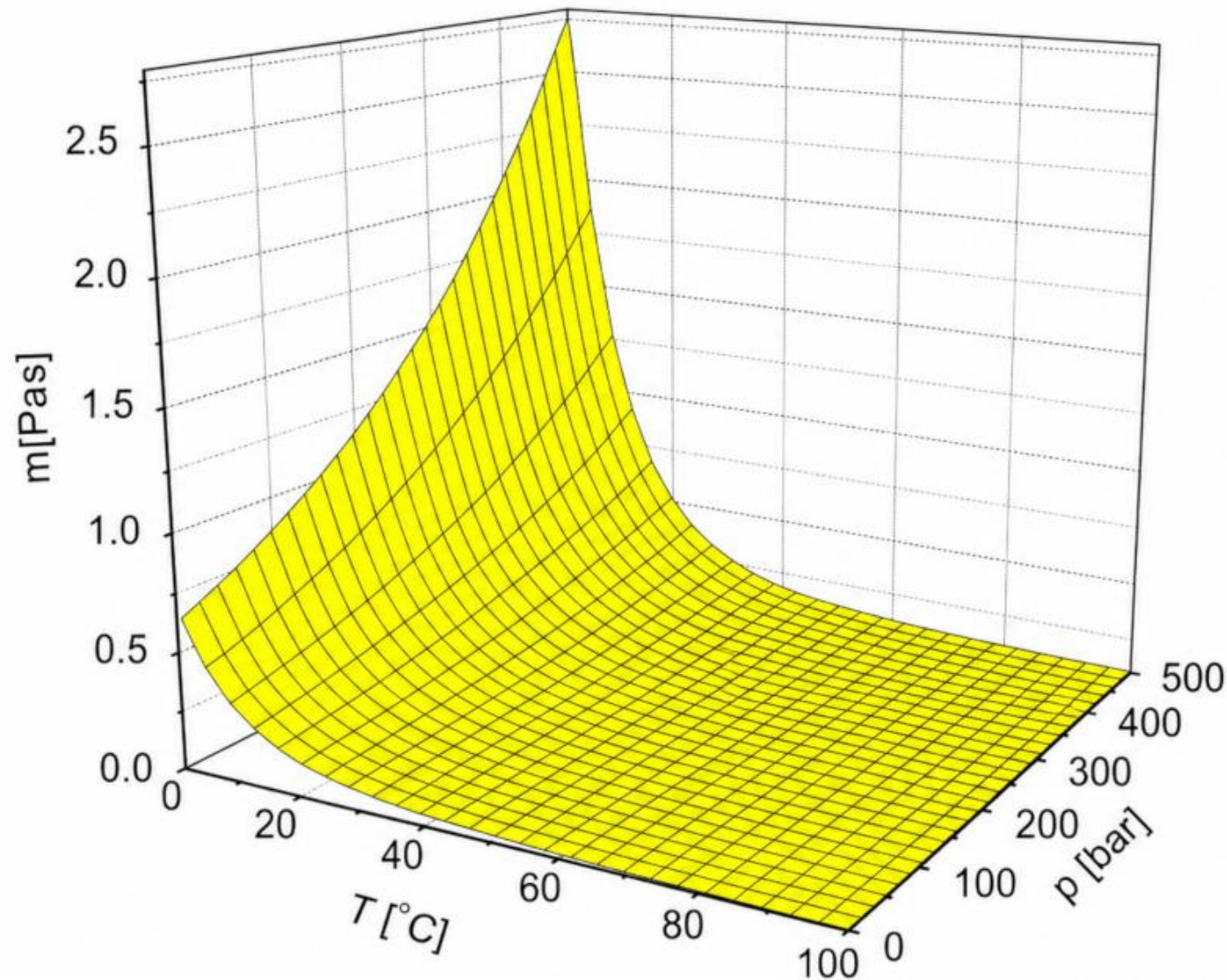
Moving_mass =
 Truck_arm_mass + Load_mass

Work =
Distance ~=
 Gyro_x

Work ~=
 Force * Gyro_x



Viscosity of Hydraulic Oil





Linear Approximation of Viscosity

Viscosity_force \approx exp(Pressure / Temperature)

Viscosity_force \approx

Coeff_0 +
Coeff_1 * Pressure / Temperature +
Coeff_2 * Pressure / Temperature ^ 2 +
Coeff_3 * Pressure / Temperature ^ 3 +
Coeff_4 * Pressure / Temperature ^ 4



Physical Model

$$\text{Friction_work} = (F0)*gx + (F1)*gx*\text{Load_mass}$$

$$\text{Gravity_work} = (G0)*ay*gx + (G1)*ay*gx*\text{Load_mass}$$

$$\text{Viscosity_work} =$$

$$(V0)*c1*gx^2 + (V1)*c1*gx^2/t1 + (V2)*c1*gx^2/t1^2 +$$
$$(V3)*c1*gx^2/t1^3 + (V4)*c1*gx^2/t1^4 +$$

$$(D0)*c2*gx^2 + (D1)*c2*gx^2/t2 + (D2)*c2*gx^2/t2^2 +$$
$$(D3)*c2*gx^2/t2^3 + (D4)*c2*gx^2/t2^4$$

$$\text{Pump_work} = p1*gx + (P2)*p2*gx$$

$$gx = \text{gyro.x} \quad ay = \text{acceleration.y}$$
$$p1 = \text{lift_pressure} \quad p2 = \text{drop_pressure}$$
$$t1 = \text{lift_temperature} \quad t2 = \text{drop_temperature}$$

$$c1 = \exp(p1 / (334 + 3.2557*t1))$$

$$c2 = \exp(p2 / (334 + 3.2557*t2))$$



Coefficients for Regression Fit

```
Friction    -->  F0 F1
Gravity     -->  G0 G1
Viscosity   -->  V0 V1 V2 V3 V4  D0 D1 D2 D3 D4
Pump        -->  P2
```

Calculated from several callibration measurements
for each setup :

- Downhill truck with cold oil.
- Uphill truck with cold oil.
- Downhill truck with hot oil.
- Uphill truck with hot oil.

Matrix inversion algorithm.

Float numbers comparison.



Gradient Descent Search for Setup Parameters

Orient_axis_y_to_movement_angle

Rotate coordinate system around axis x , such that axis y is in the direction of movement of center of gravity of the moving mass.

Smooth_time

The window size for the smooting of the raw signal data, such that spring oscillation effects are cleared.

Mesurement_angle_begin_angle

Mesurement_angle_angle_length

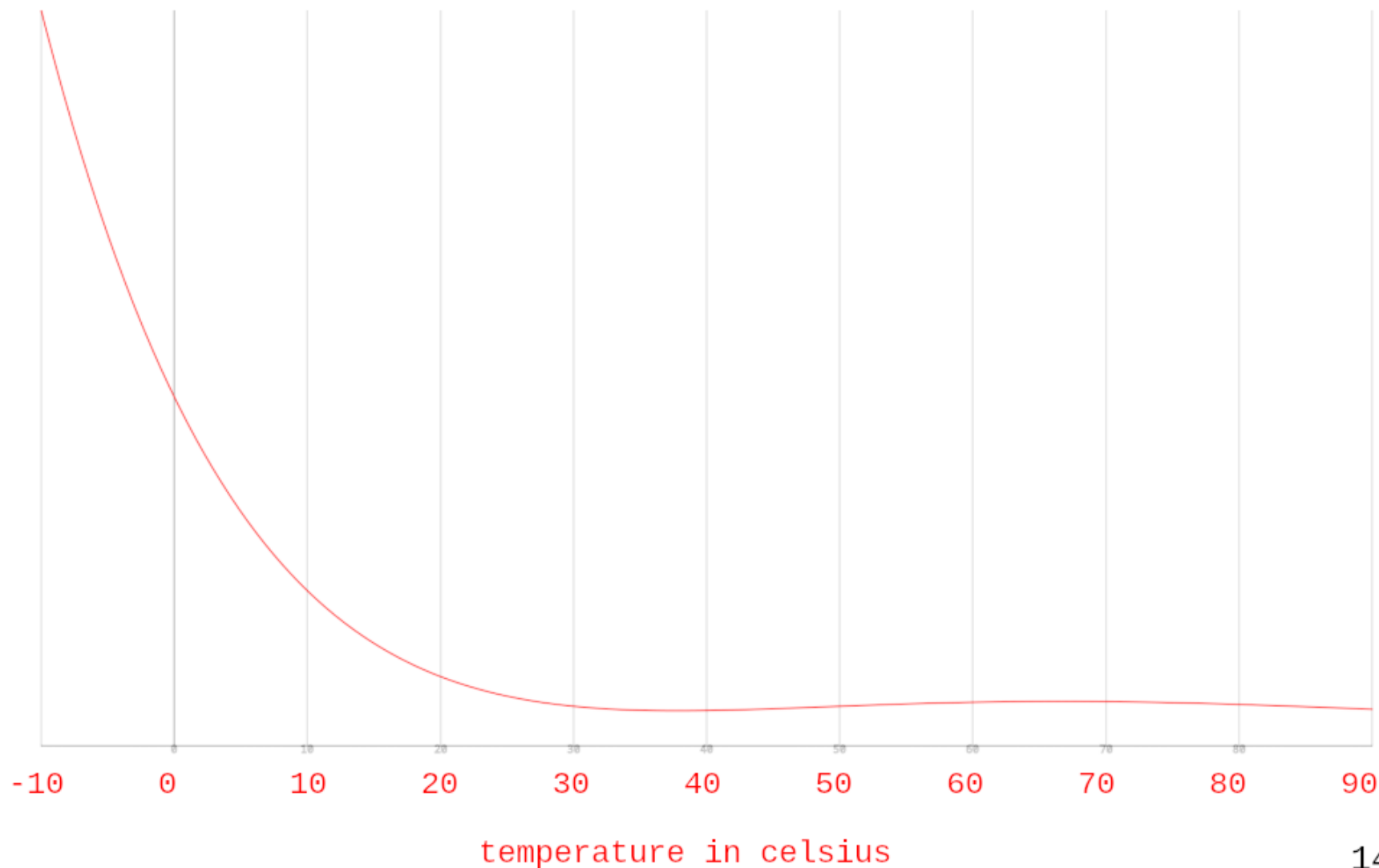
The angle interval where the physical model is calculated. Inside the `valid_angles`.

Temperature_delay

Delay for the raw temperature signal so the time it takes for heating and cooling of the termometer is accounted.

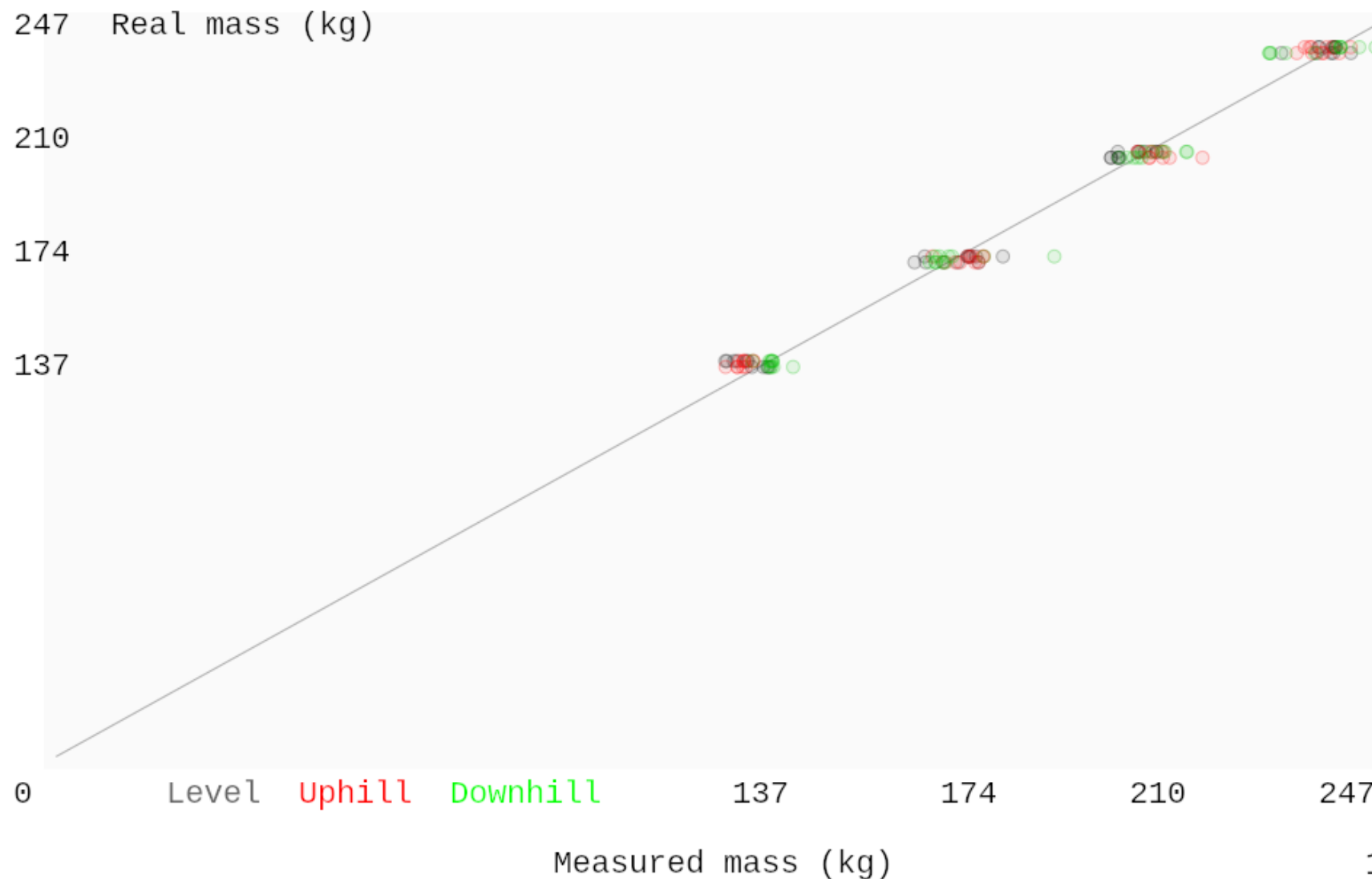


Viscosity Fit Curve





Results Plot





Results

Real mass	Err	Csv name
248.05	-6.07	uphill__steel_12__248.05kg__hot.angle.csv
211.45	1.03	uphill__steel_08__211.45kg__hot.angle.csv
174.85	2.74	uphill__steel_04__174.85kg__hot.angle.csv
138.25	-3.21	uphill__steel_00__138.25kg__hot.angle.csv
138.25	.22	downhill__steel_00__138.25kg__hot.angle.csv
174.85	18.59	downhill__steel_04__174.85kg__hot.angle.csv
211.45	7.55	downhill__steel_08__211.45kg__hot.angle.csv
248.05	1.00	downhill__steel_12__248.05kg__hot.angle.csv
248.05	-.38	level__steel_12__248.05kg__hot.angle.csv
211.45	1.71	level__steel_08__211.45kg__hot.angle.csv
174.85	-6.54	level__steel_04__174.85kg__hot.angle.csv
138.25	-8.28	level__steel_00__138.25kg__hot.angle.csv
...		

Avg Mes err 3.50 kg

Total Actual 25236.60 kg

Total Mes 25167.35 kg