



Съфинансирано от  
Европейския съюз



# Physical Modeling of a Lifting System Using Hydraulic Pressure and Inertial Measurement Sensors

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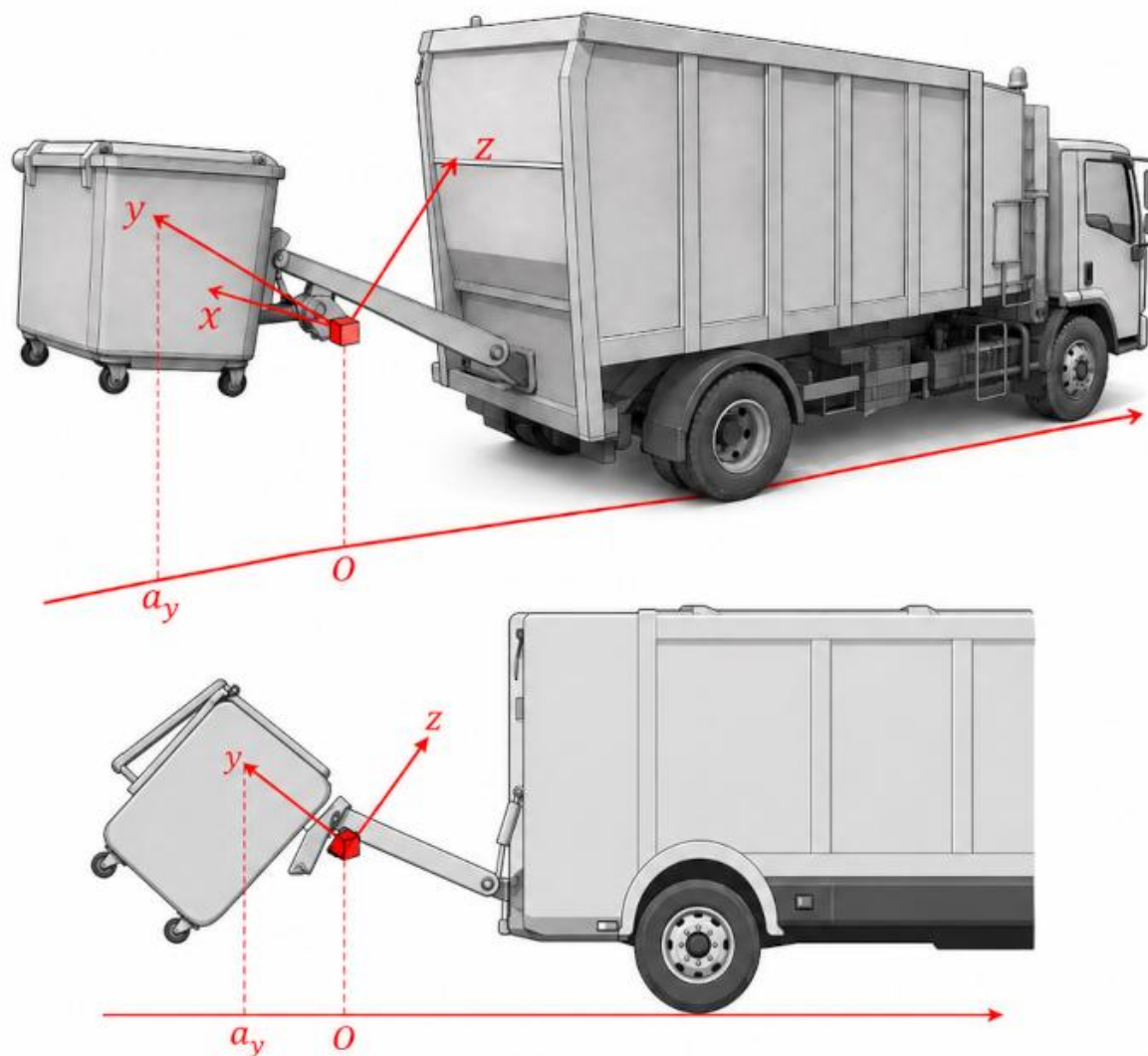
Reference :

[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.

*Проект BG16RFPR001-1.001-0012-C01 „Интелигентно зелено измерване и анализ на разделно събирани отпадъци“, финансиран от Програма „Конкурентоспособност и иновации в предприятията“ 2021-2027, съфинансирана от Европейския съюз*



## IMU Sensor Coordinate System





## Raw Data

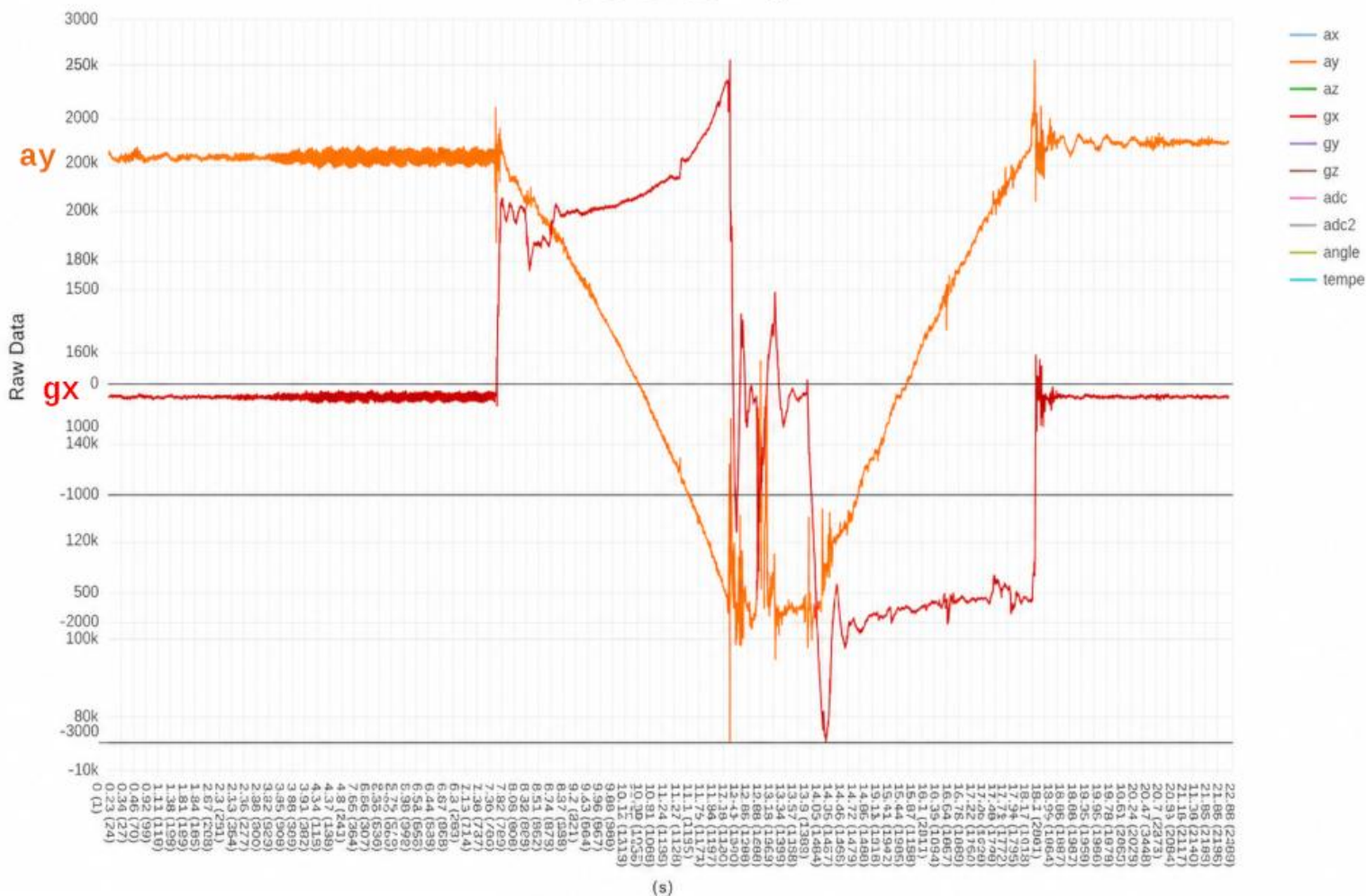
Example CSV data file content :

```
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  
...
```



# Raw Data Plot

07\_00\_27\_steel\_152.10kg.csv





# Rotation Angle

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

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

Remove **gyro** drift.

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

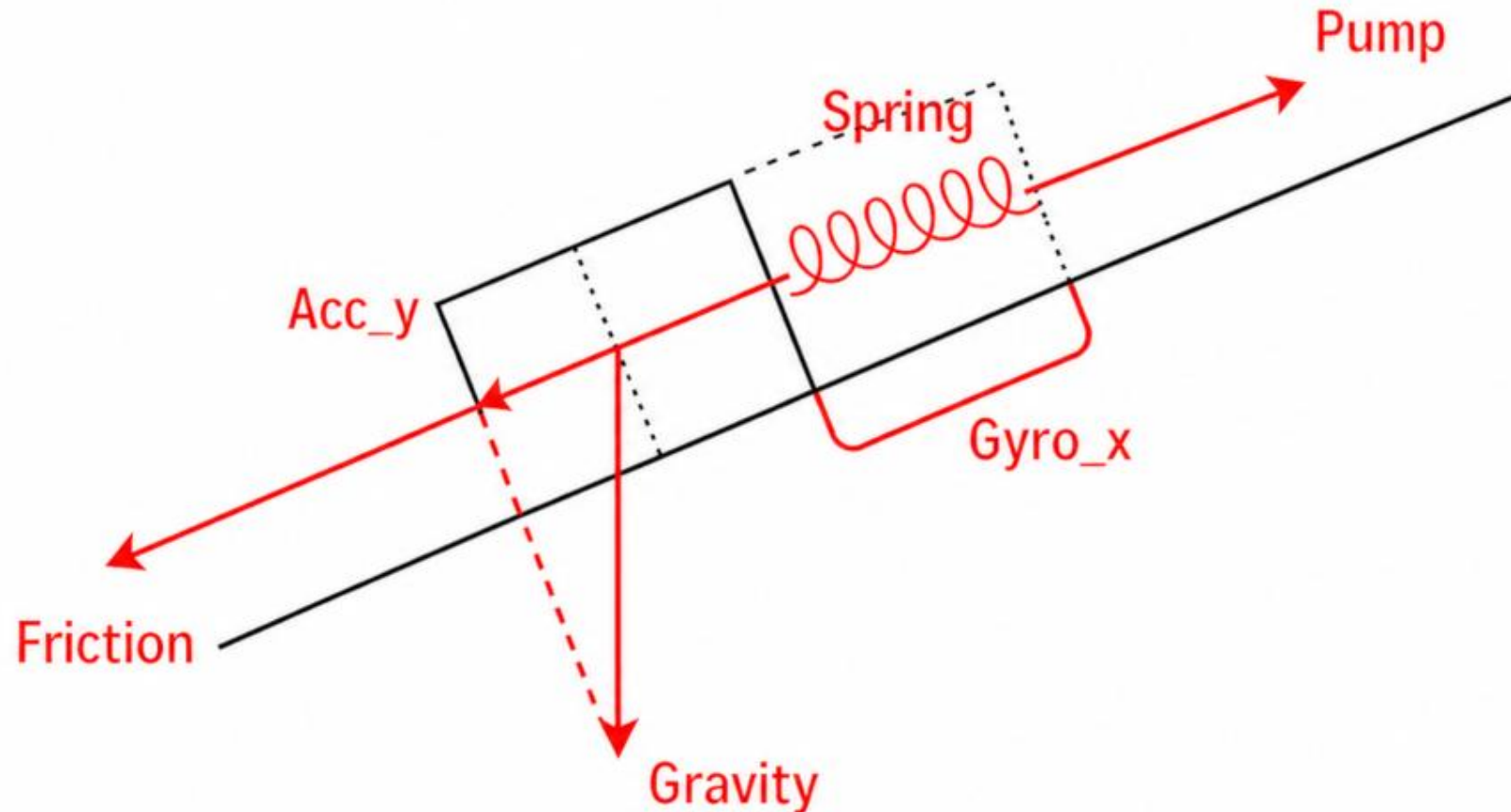
Not constant during the whole dump movement.  
For choosing rotation axis  
, hand select an interval from the plot.

Calculate **angles**, integraging **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`.

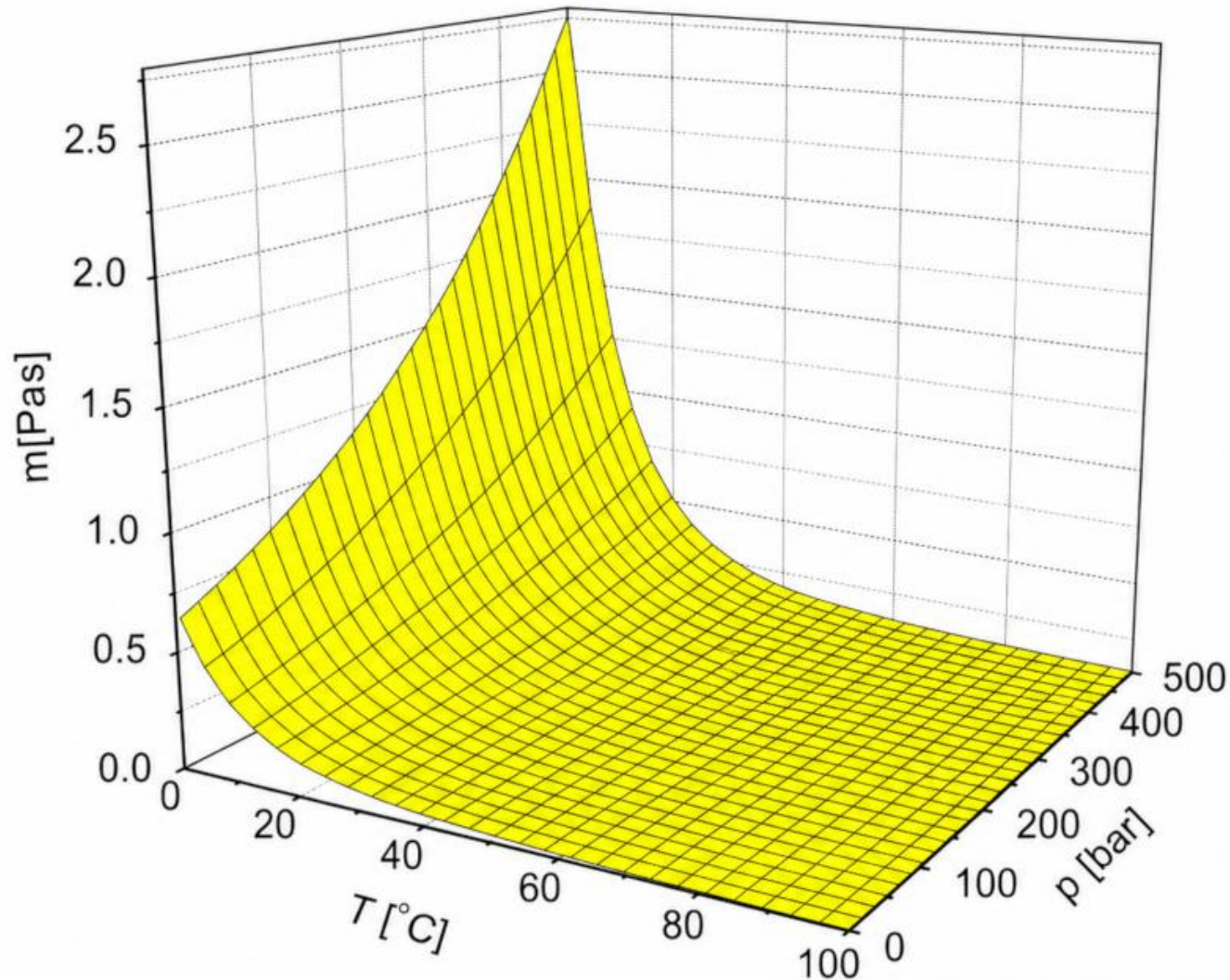
## Smooth\_time

For removing the vibrating spring effect.





## 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

$$\text{Friction\_work} = (F0) * gx + (F1) * gx * \text{Load\_mass}$$

$$\text{Gravity\_work} = (G0) * ay * gx + (G1) * ay * gx * \text{Load\_mass}$$

$$\text{Viscosity\_work} =$$

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

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

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

$$gx = gyro.x \quad ay = acceleration.y$$
$$p1 = \text{lift\_pressure} \quad p2 = \text{drop\_pressure}$$
$$t1 = \text{lift\_temperature} \quad t2 = \text{drop\_temperature}$$

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

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



# 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.