Electric Vehicle Power Control

Backgrounds

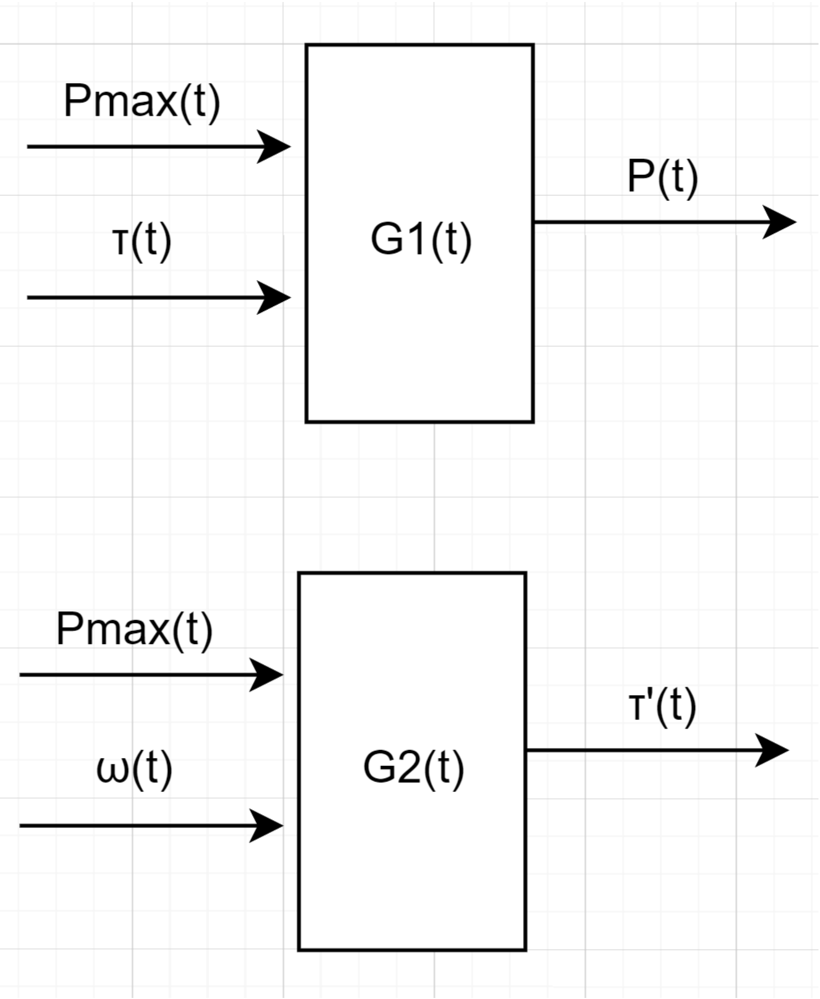
- After using the supercapacitor, it will unconditionally compensate for the additional chassis power. *Buffer energy is no longer reliable.*

- But to prevent the energy of the supercapacitor from being consumed, we need an algorithm to keep the power below the target power.

Workable method

- Sampling the current of each motor installation to get the exact power of the motor.
  - Complex hardware and low reliability

- Calculation of the expected motor power consumption by modeling the existing feedback values. (Torque, RPM).


Pmax(t)
τ(t)
G1(t)
P(t)
Pmax(t)
ω(t)
G2(t)
τ'(t)

Give Current, Given Current, Real Current & Moment

- Give Current - Control commands sent to the motor. No unit
- Given Current – C620 Feedback Value No unit
- Real Current - Actual current consumption of the motor.

Physical meaning

- The physical significance of Give Current and Given Current is torque current. Unit (A).
- It is used to describe the magnitude of the current that provides the moment.
- It is proportional to the moment.

Derivation of torque versus give current

- The range of the give current value is -16384~0~16384, corresponding to the give torque current of the C620 is -20A~0~20A.

$$I_\tau = \frac{20}{16384} \times n$$

I_τ is the torque current in A and n is the ESC give current.

- We can't use the torque current multiplied by the voltage to get the input power of the motor, the relationship between torque current and torque is as follows.

$$\tau = K_T \times I_\tau$$

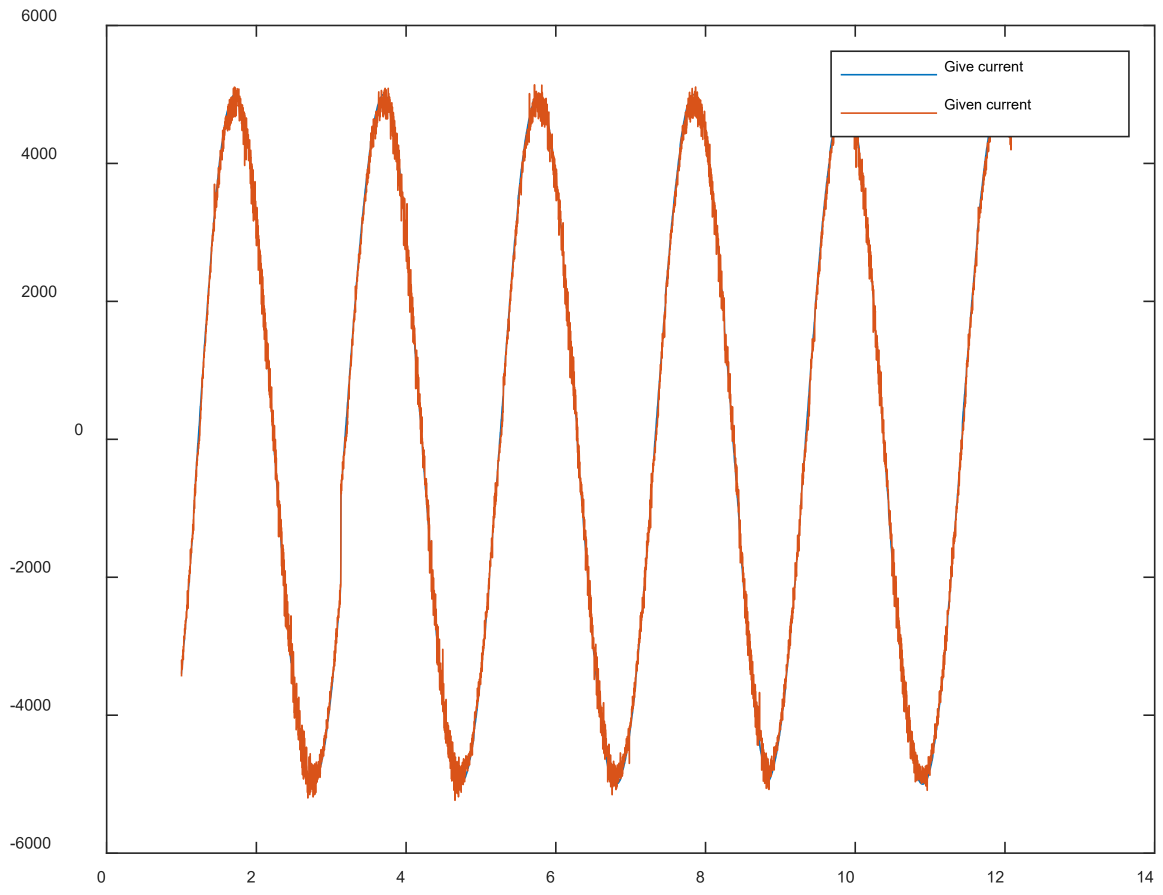
- K_T is torque constant.
- The torque constant in the manual describes the torque of the output shaft of the motor gearbox. Since the feedback from the motor is the rotor speed, in order to facilitate the calculation, we need to get the torque constant of the motor rotor through the calculation of the reduction ratio here.

Characteristic Parameters	
Rated Voltage	24 V
Torque Constant	0.3 N·m/A
Speed Constant	24.48 rpm/V
Speed/Torque Gradient	72 rpm/N·m
Mechanical Time Constant	49 ms
Phase Resistance	0.194 Ω
Phase Inductance	0.097 mH
Operating Temperature Range	32°~122° F (0°~50° C)
Max Permissible Winding Temperature	257° F (125° C)
Number of Pole Pairs	7
KN	210 N
Weight	365 g
Reduction Ratio	3591/187

- $K_T = 0.3 \times \frac{187}{3591} = 0.01562\ \mathrm{N \cdot m/A}$

- give current -> give torque current -> give torque
- given current -> given torque current -> given torque

- For ease of description, all are analyzed next using torque



Specification

- Torque in counterclockwise direction is positive, torque in clockwise direction is negative.
- Rotation speed in counterclockwise direction is positive and rotation speed in clockwise direction is negative.
- Power is positive for power consumption and power is negative for power output.

Motor power composition

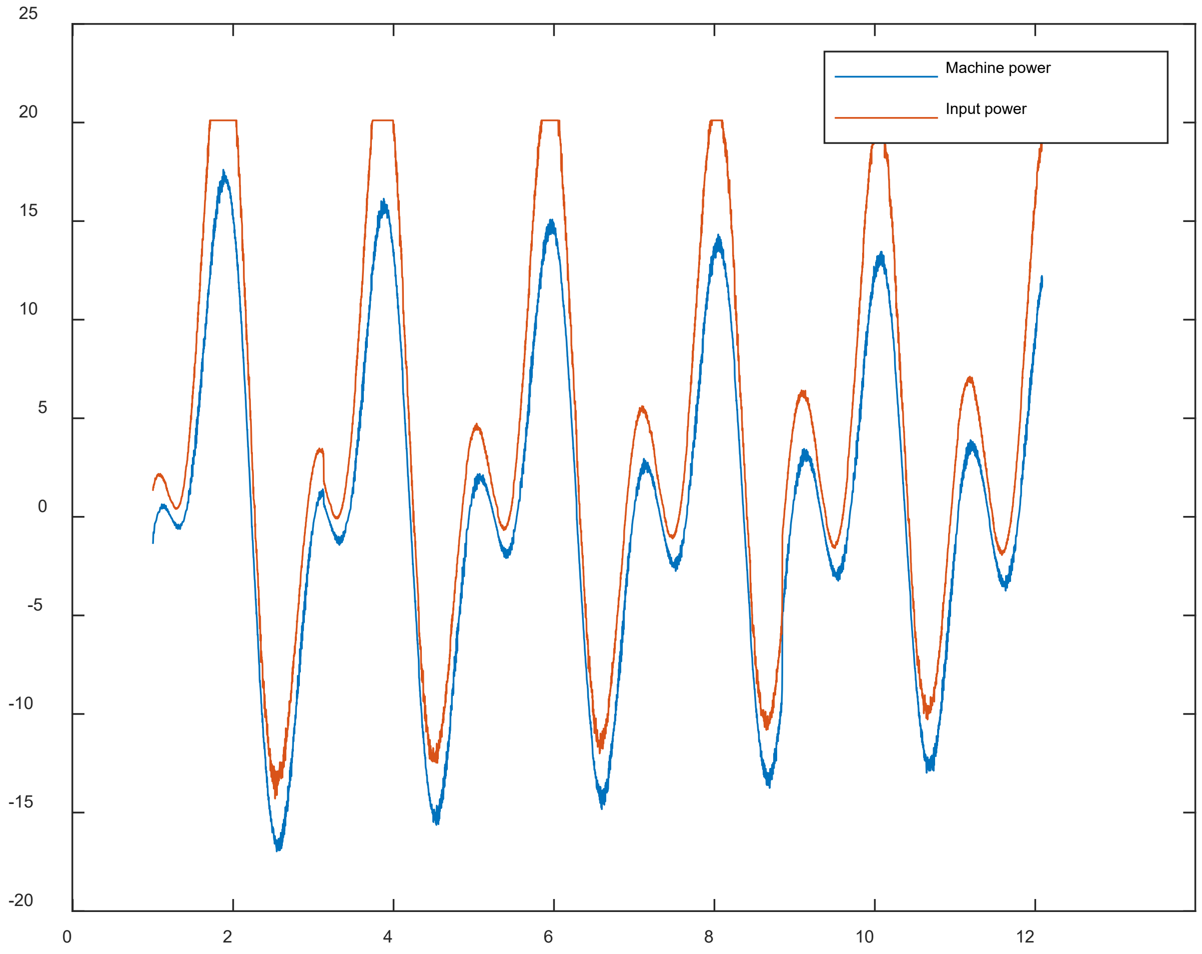
- The input power of a brushless motor is mainly composed of mechanical power, copper loss, magnetic loss, and static power consumption of the controller.
- Among them, the mechanical power accounts for the main part：

$$P_m = \frac{\tau\omega}{9.55}$$

- ω is the rotor speed in RPM

Problems with the previous algorithm

- The power consumption of a motor is not only related to the torque, but also to the current speed of the motor.

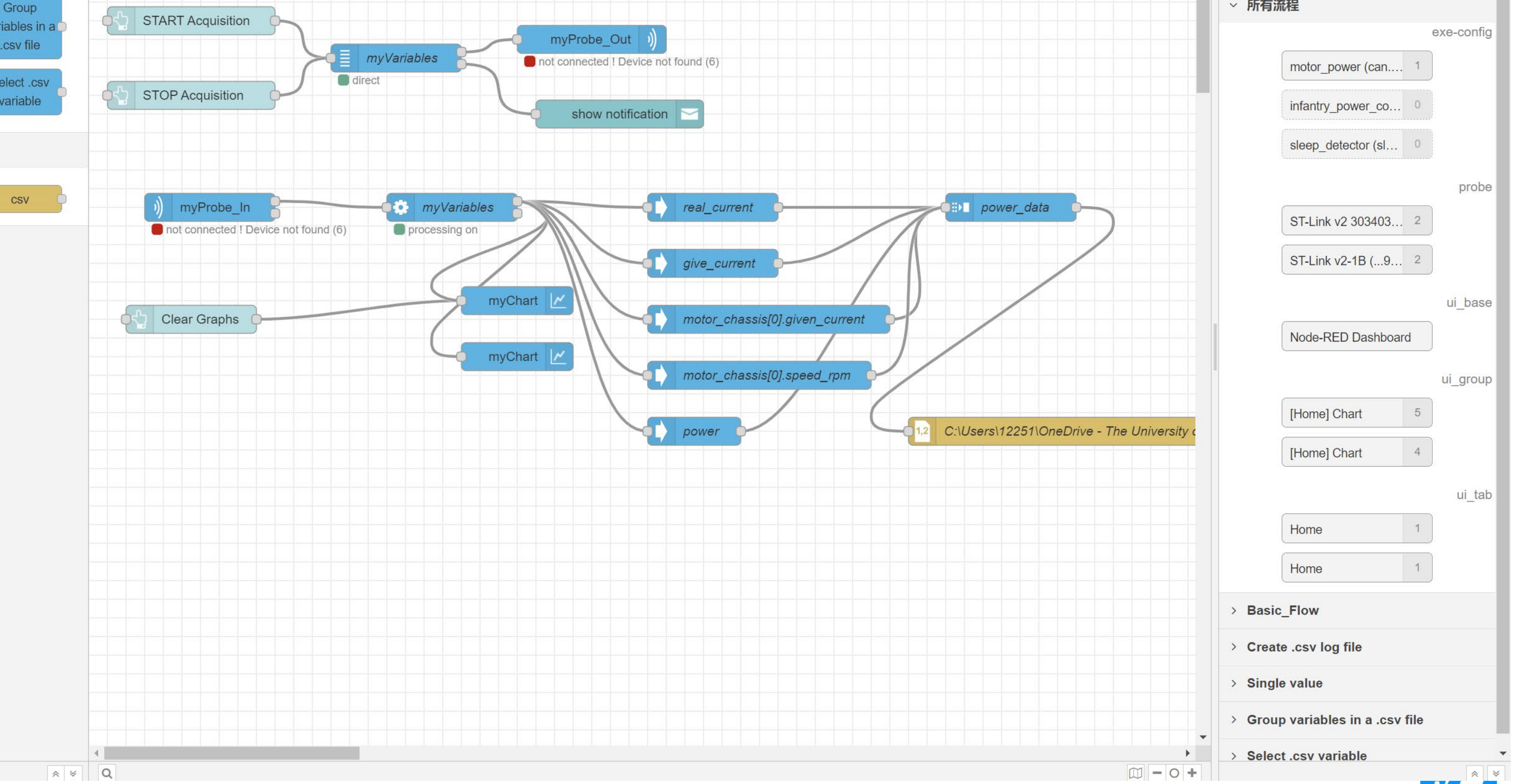


Model expression

$$P_{in} = P_m + k_1\omega^2 + k_2\tau^2 + a$$

- The formula is widely used in RoboMaster.

- Presumably, this is because the other teams found a strong correlation with the two quadratic terms when fitting for power, and chose to keep only these two variables.



Group
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.csv file
elect .csv
variable
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START Acquisition
STOP Acquisition
myVariables
direct
myProbe_Out
not connected ! Device not found (6)
show notification
myProbe_In
not connected ! Device not found (6)
myVariables
processing on
real_current
give_current
motor_chassis[0].given_current
motor_chassis[0].speed_rpm
power
power_data
myChart
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Clear Graphs
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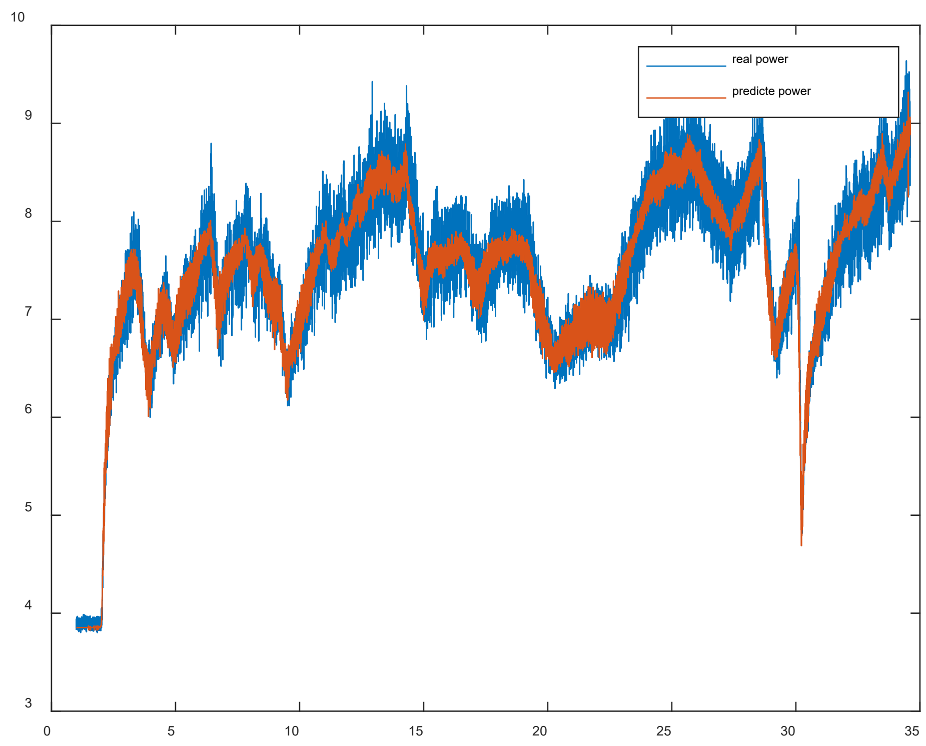
exe-config
motor_power (can… 1
infantry_power_co… 0
sleep_detector (sl… 0
probe
ST-Link v2 303403… 2
ST-Link v2-1B (...9… 2
ui_base
Node-RED Dashboard
ui_group
[Home] Chart 5
[Home] Chart 4
ui_tab
Home 1
Home 1
Basic_Flow
Create .csv log file
Single value
Group variables in a .csv file
Select .csv variable

Fitting result

- Equation fitting using matlab's fit and fittype functions



- Substituting Pin into the model

$$k_1\tau^2 + \frac{\omega\tau}{9.55} + k_2\omega^2 + a - P_{in} = 0$$

- Observing that the equation is a quadratic equation about the torque, and that all other quantities are known quantities, solving for the torque, we get

$$\tau = \frac{-\frac{\omega}{9.55} \pm \sqrt{\left(\frac{\omega}{9.55}\right)^2 - 4k_1(k_2\omega^2 + a - P_{in})}}{2k_1}$$

Multiple solutions problem

- Here both solutions make sense. It is not possible to keep only *one solution* and then reassign it according to the direction of the original moments.

- At the same moment, there are indeed two values of torque, one positive and one negative, which cause the motor to consume a power of Pmax!

$$\tau = \frac{-\frac{\omega}{9.55} \pm \sqrt{\left(\frac{\omega}{9.55}\right)^2 - 4k_1(k_2\omega^2 + a - P)}}{2k_1}$$

The power control algorithm based on this model

- Uniform distribution of one quarter of the maximum power to each motor
  - Wasted power, can't walk in a straight line.
- All into absolute values, and then set the scaling factor K and perform the calculation.
  - Calculations are biased.
  - Wasting the motor's counter electromotive force.

我们根据(2)式来实现功率限制。已知：最大功率 P_{max}、各电机当前转速 ω_{real} 和电机 PID 计算出来的原始力矩指令 τ_{cmd} 。当 τ_{cmd} 将使 P_{in} 高于 P_{max} 时，设有一缩放系数 k，令 $\tau'_{cmd} = k\tau_{cmd}$, 使得 τ'_{cmd} 满足：

$$P_{max} = \sum |\omega_{real}\tau_{cmd'}| + k_1 \sum \tau'^2_{cmd} + k_2 \sum \omega'^2_{real}$$

则可由上式计算出 k 的值：

$$k = \frac{-\sum|\omega_{real}\tau_{cmd}| + \sqrt{\sum(\omega_{real}\tau_{cmd})^2 - 4k_1(\sum\tau^2_{cmd})(k_2\sum\omega^2_{real} - P_{max})}}{2k_1\sum\tau^2_{cmd}}$$

最终给电机的力矩指令即为 $\tau'_{cmd} = k\tau_{cmd}$。

Power redistribution

The algorithm is first used to forward calculate the power of each motor to obtain the power scaling factor k

$$k = \frac{P_{max}}{\Sigma P_{cmd}}$$

Let $\mathrm{P_{in}} = k \times P_{cmd}$, bring in the formula to find the new moment.

Selection of the solution according to the direction of the original moment

Complete Control Block Diagram