BTP FINAL PPT 2021

VRFT Control on Pendulum Systems

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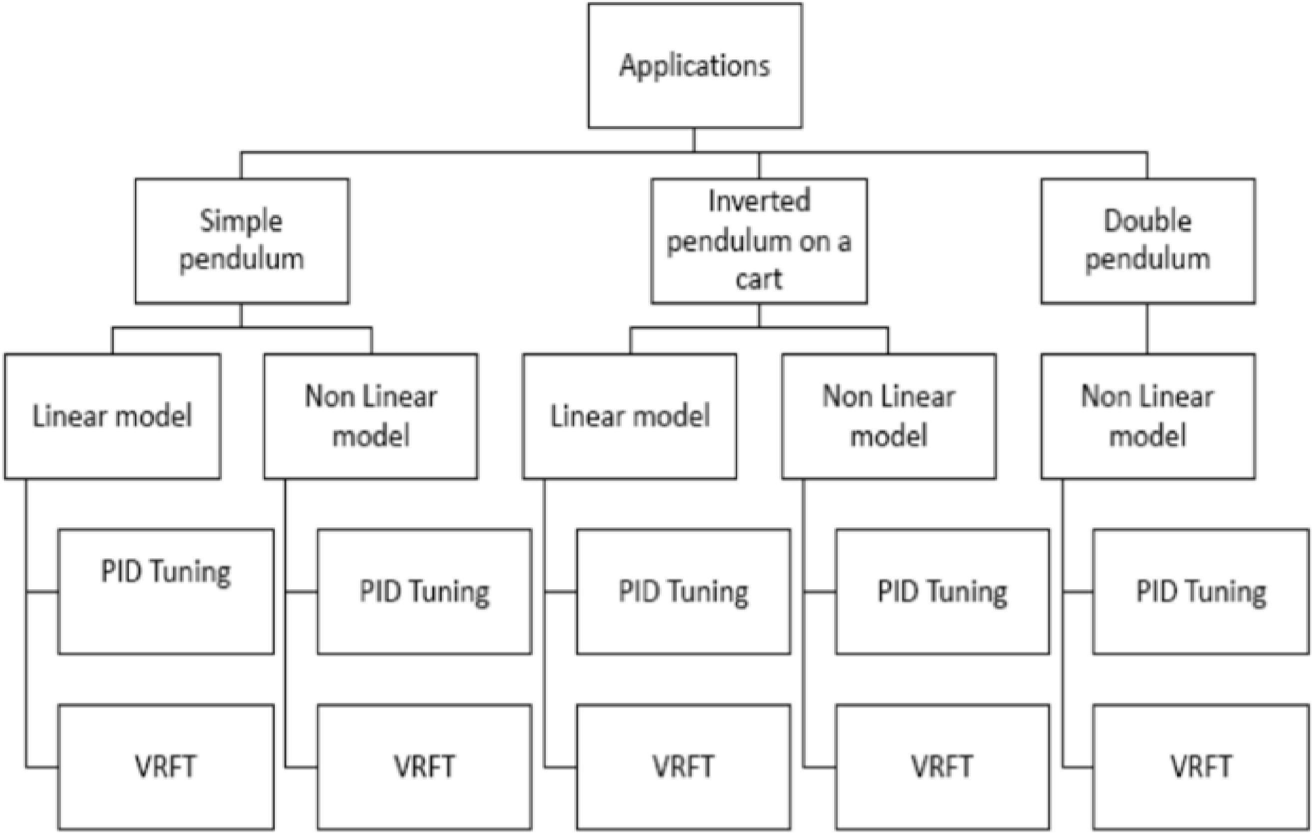
OBJECTIVES

- Understanding the VRFT needs to be applied on Pendulum Systems
- Deriving and plotting the differential equations of motion for Simple Pendulum
- VRFT Control and PID Tuning Algorithm for Simple Pendulum
- Deriving and plotting the differential equations of motion for Inverted Pendulum
- VRFT Control and PID Tuning Algorithm for Inverted Pendulum
- Deriving and plotting the differential equations of motion for Double Pendulum
- VRFT Control and PID Tuning Algorithm for Double Pendulum
- Comparing the results from VRFT Control with PID Tuning Method

Work Done

Flow chart for our work



VRFT Control

VRFT is a data-driven method that allows you to choose a controller based on data alone, without the requirement for a plant model.
It is a straightforward procedure in which no model identification of the plant is needed.
It can be used with a single set of data received from the plant, and no specific experiments or iterations are required.

Designing algorithm

1. Given or chosen : $M(z)$, $C(z, \theta)$, $\{ u(t), y(t) \}_{t = 1,2,\ldots,N}$
2. Calculate $M(z).r(t) = y(t)$ and $e(t) = r(t) - y(t)$
3. Filter L(z) or we can set pre-filter is equal to 1

$$e_L(t) = L(z).e(t)$$

$$u_L(t) = L(z).u(t)$$

4. Select θ_N so that cost function should be minimized

$$J^N{}_{VR}(\theta) = \frac{1}{N}\sum_{i=1}^{N}\left(u_l(t) - C(z,\theta)\cdot e_l(t)\right)^2$$

Simple Pendulum

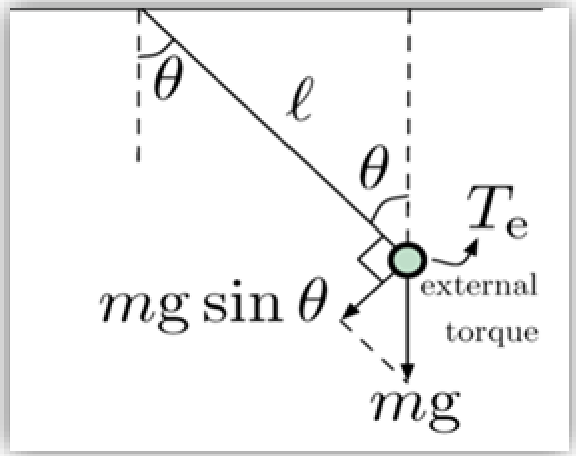


Fig. Schematic diagram of simple pendulum

Nonlinear Equation of motion:

$$\ddot{\theta}(t) = -\frac{g}{L} sin(\theta) + \frac{T_e}{mL^2}$$

After linearizing the equation of motion becomes

$$\ddot{\theta}(t) = -\frac{g}{L}\theta + \frac{T_e}{mL^2}$$

Nonlinear step response of the pendulum system

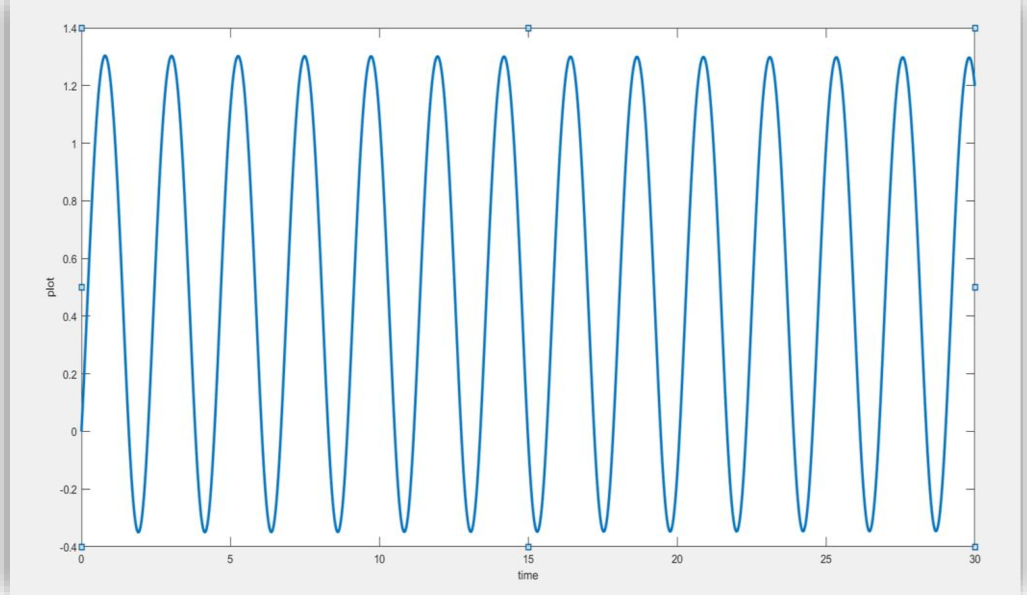


Fig1.Impulse Response of the nonlinear pendulum system

Parameters From PID Tuning Method

1.Linear model

Controller Type	K_p	K_i	K_d
P	8.274	n/a	n/a
PID	5.6847	0.022233	0.0000003

2.Non-Linear Model

Controller Type	K_p	K_i	K_d
PID	0.82225	0.029867	0
P	1.1732	0	0
I	0	0.041873	0

Response after using P and PID controller for Linear model

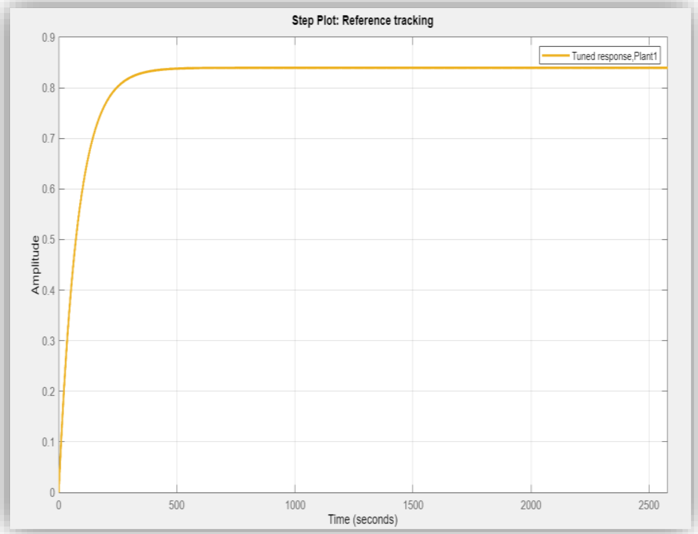


Fig1. For P controller

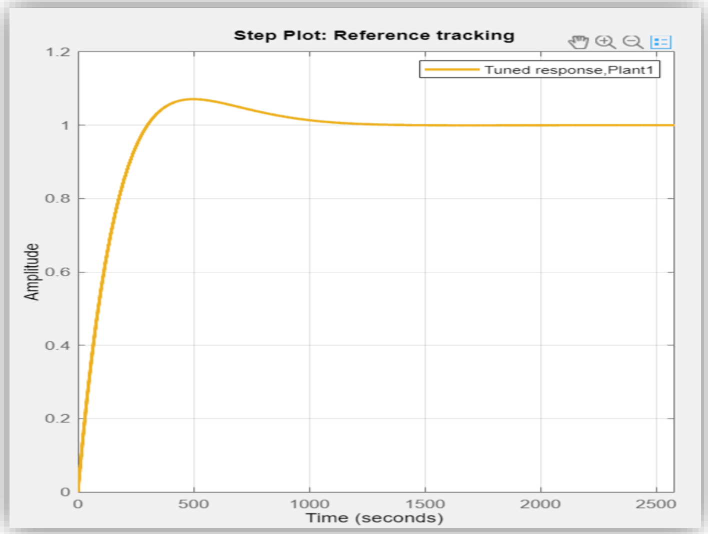


Fig2. For PID controller

Response after using P, I and PID controller for non-linear model

Fig1.For I controller

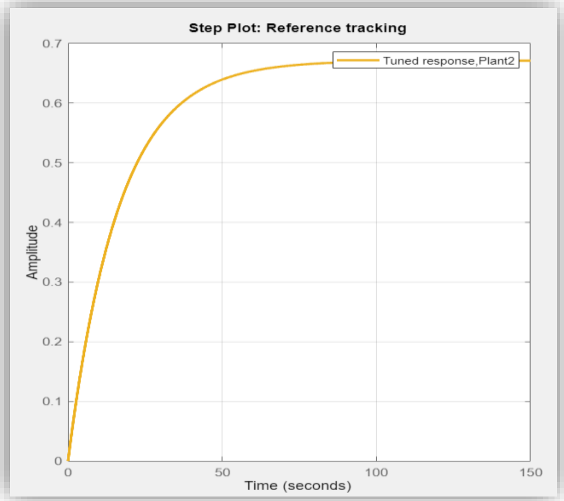


Fig2.For P controller

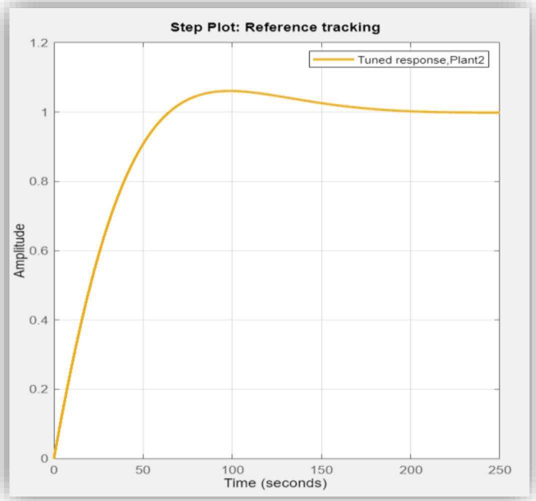


Fig3. For PID Controller

Parameters from VRFT Algorithm

1.Linear model

Controller Type	K_d	K_p	K_i
PID	0.01898263	-0.02087513	0.0181956

2.Non-Linear Model

Controller Type	K_d	K_p	K_i
P	0	0.00015683	0
PI	0	-0.0099513	0.0100749
PD	0.013433	-0.0132689	0
PID	1.0011337	-1.98791531	0.998827

Response after using P,PD,PI and PID controller for nonlinear model

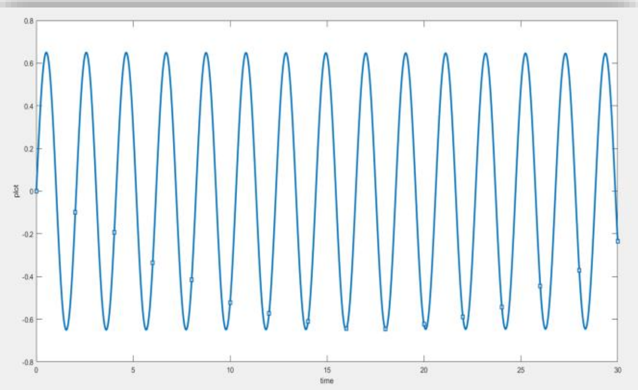


Fig1. For P controller

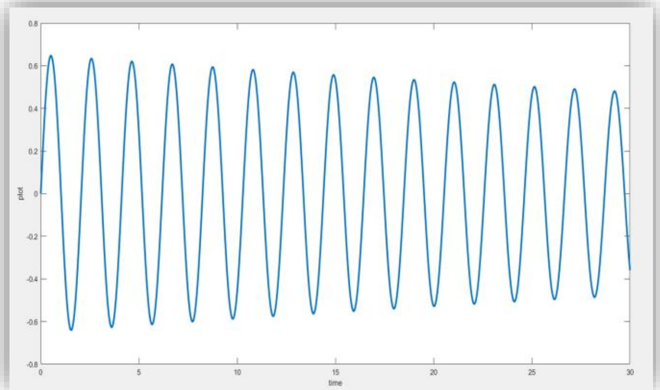


Fig2. For PD controller

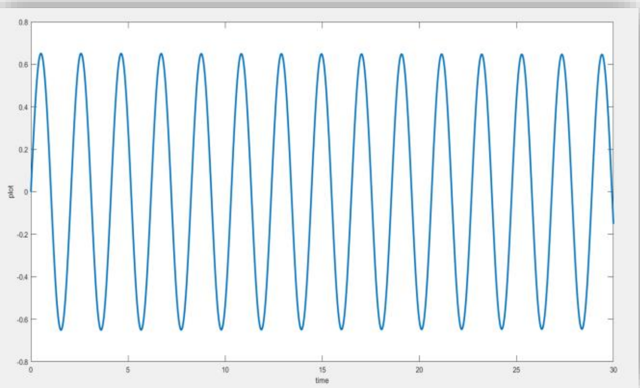


Fig3. For PI controller

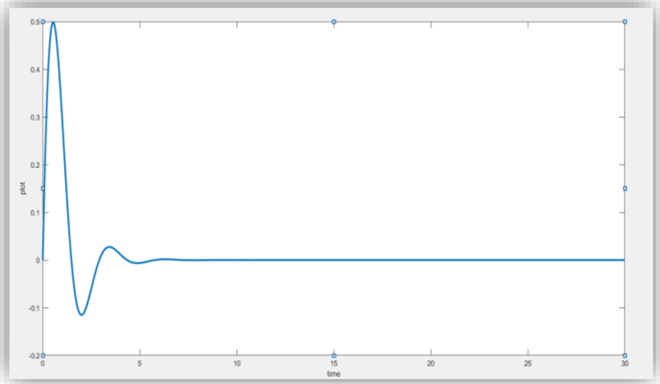


Fig4. For PID controller

Observations

- From the figures, we can see that they are quite different from what we observed in PID Tuning Algorithm.
- this can be due to the change in references and the different procedures of both algorithms to find the parameters of controllers.
- We found the parameters for P, PD, PI, PID controllers. We see different parameters in each cases.
- The system tends to stabilize faster using PID Controller than using PD Controller.
- Although, PD controllers stabilize the system after a long time.
- The P and PI controllers don’t seem to stabilize the system very well as they don’t provide damping that stabilize the system.

Inverted Pendulum on a cart

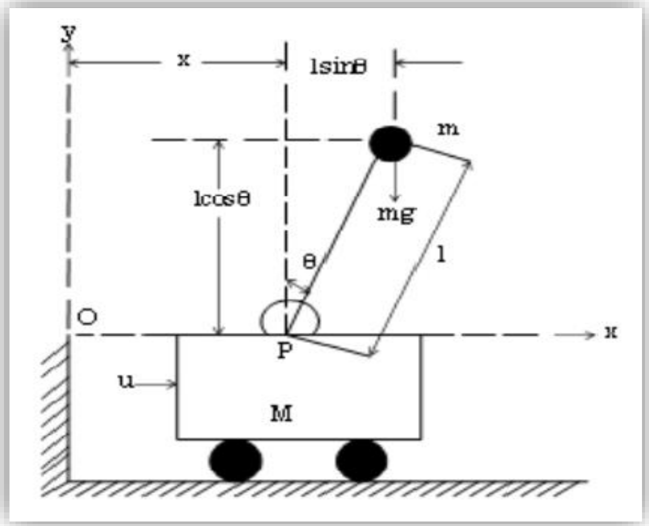


Fig. Schematic Diagram of inverted pendulum on a Cart

Equation of motion:

$$\ddot{X} = \frac{u + mlsin(\theta)\dot{\theta}^2 - mgcos(\theta)sin(\theta)}{M + m - mcos^2(\theta)}$$

$$\ddot{\theta} = \frac{ucos(\theta) + (M+m)gsin(\theta) + ml((cos(\theta)sin(\theta))\dot{\theta}^2}{mlcos^2(\theta) - (M+m)l}$$

Non-linear step response of the Inverted pendulum system

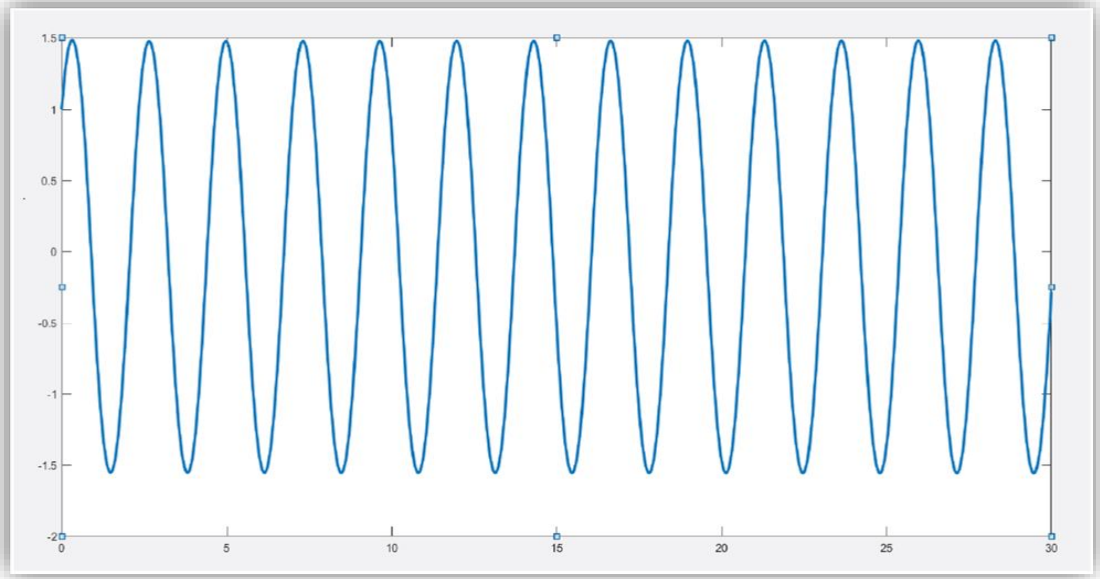


Fig1.Impulse Response of the non-linear pendulum system

Parameters from PID tuning method

1.Linear model

Controller Type	K_p	K_i	K_d
P	3.43806264e-24	0	0
I	0	5.5797e-26	0
PD	3.9976e-24	NA	0
PID	2.8e-24	3.98e-26	0

2.Nonlinear model

Controller Type	K_p	K_i	K_d
P	0.0098002	0	0
I	0	0.00034979	0
PID	0.0068687	0.0002495	0

Response after using P,I,PD and PID controller for linear model

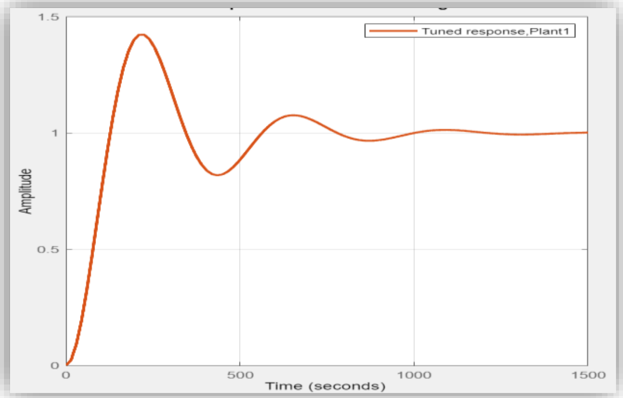


Fig1.For I controller

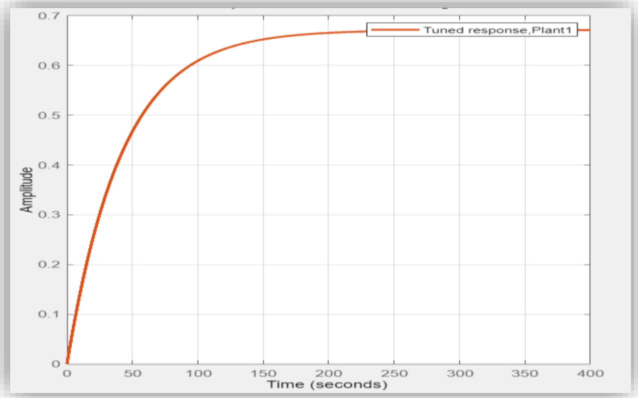


Fig2. For P controller

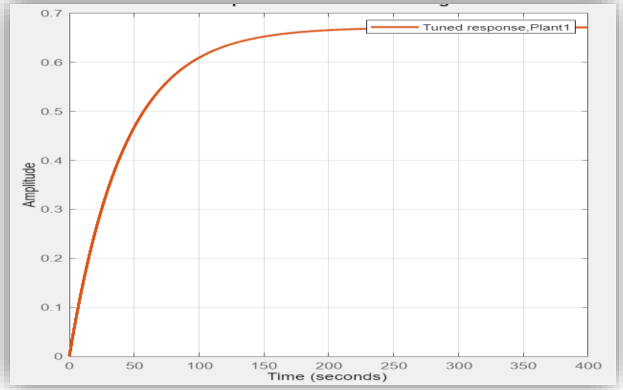


Fig3. For PD controller

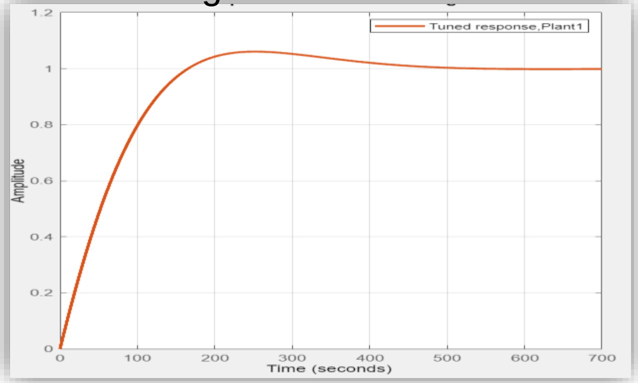


Fig4. For PID controller

Response after using P, I and PID controller for non-linear model

Fig1. For P controller

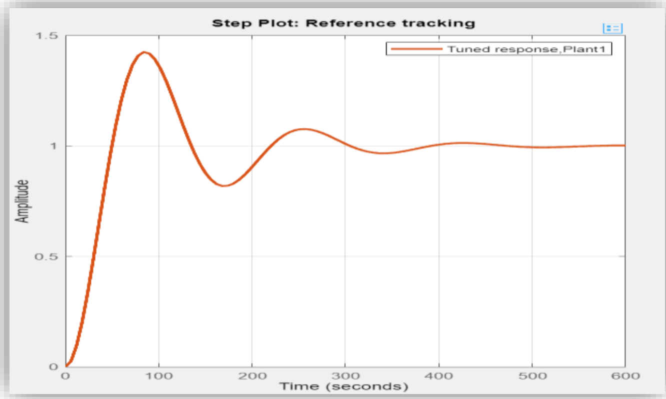


Fig2. For I controller

Fig3. For PID controller

Parameters From VRFT Method

1.Linear model

Controller Type	K_d	K_p	K_i
PID	-0.03885	0.06144325	-0.3217711

2.Nonlinear model

Controller Type	K_d	K_p	K_i
PD	0.1376276	-0.171969	0
PI	-0.3615385	0	-0.3603846
PID	-97.537377	194.586162	-97.781841

Response after using PD,PI and PID controller for non-linear model

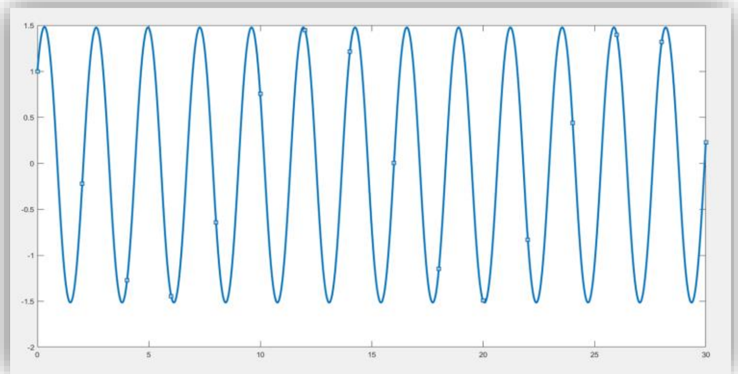


Fig2. For PI controller

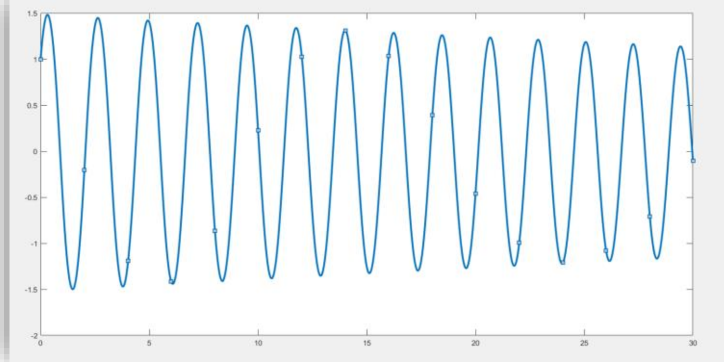


Fig1. For PD controller

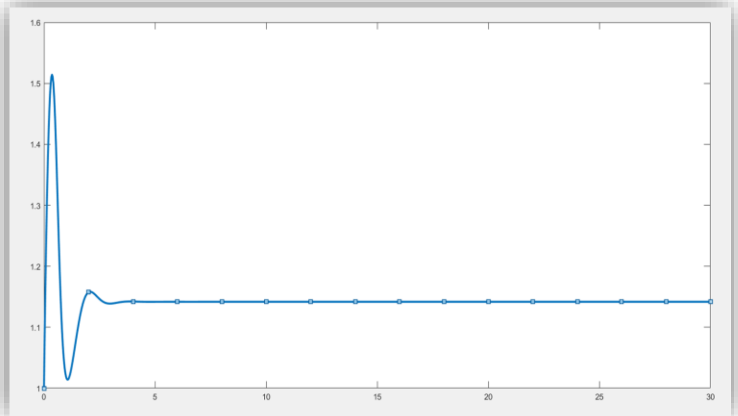


Fig3. For PID controller

Double pendulum

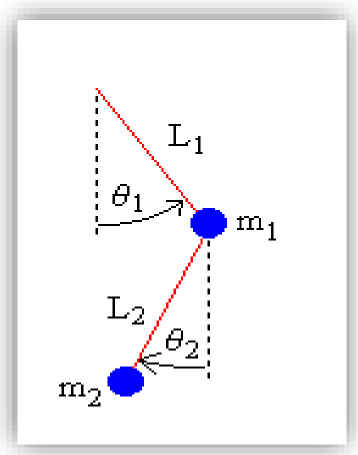


Fig. Schematic diagram of double pendulum

Nonlinear Equation of Motion is given below

$$\ddot{\theta}_1(t) = \frac{-g(2m_1+m_2)sin(\theta_1 - m_2 g sin(\theta_1 - 2\theta_2) - 2sin(\theta_1-\theta_2)m_2(\dot{\theta}_2^2 L_2 + \dot{\theta}_1^2 L_1 cos(\theta_1-\theta_2))}{L_1(2m_1+m_2-m_2 cos(2\theta_1-2\theta_2))}$$

$$\ddot{\theta}_2(t) = \frac{2sin(\theta_1-\theta_2)(\dot{\theta}_1^2 L_1(m_1+m_2)+g(m_1+m_2)cos(\theta_1)+\dot{\theta}_2^2 L_2 m_2 cos(\theta_1-\theta_2))}{L_2(2m_1+m_2-m_2 cos(2\theta_1-2\theta_2))}$$

Nonlinear step response of the Inverted pendulum system

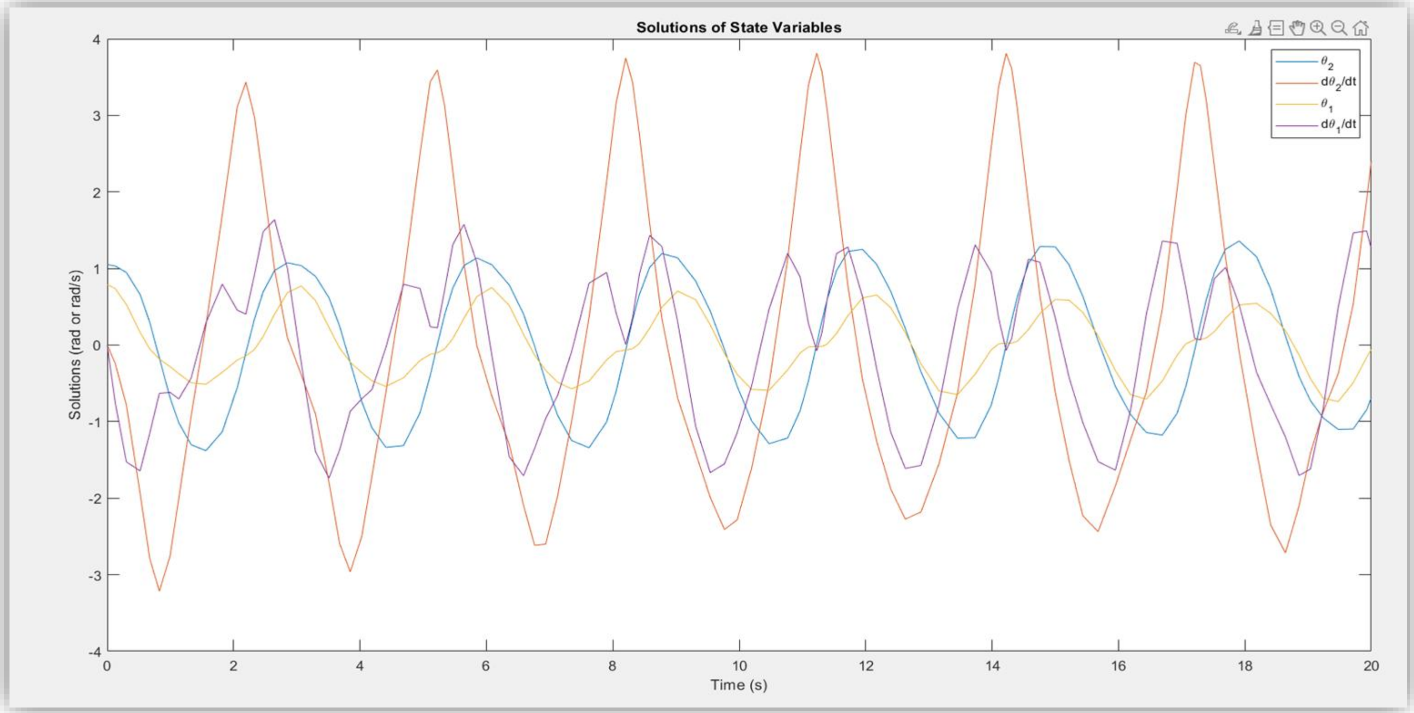


Fig1.Impulse Response of the non-linear pendulum system

Results from PID tuning for non-linear model

1. For θ_1

Controller Type	K_p	K_i	K_d
P	-1.4808	NA	0
I	0	-0.24419	NA
PI	-0.75571	-.021	NA
PID	-1.0378	-0.17418	0

2.For θ_2

Controller Type	K_p	K_i	K_d
P	2.6007	NA	NA
I	NA	0.42887	NA
PI	1.3272	0.36882	NA
PID	1.8227	0.30591	0

Response after using P,I,PD and PID controller for Linear model for θ_1

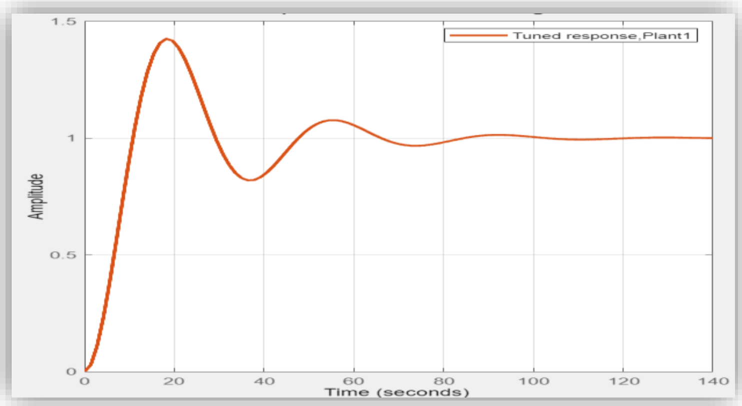


Fig1. For I controller

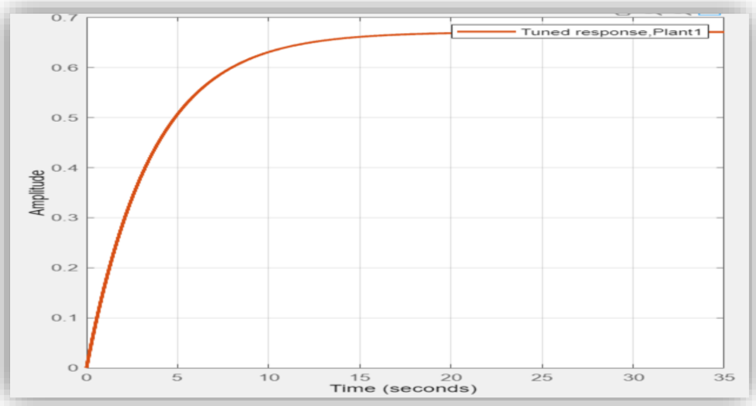


Fig2. For P controller

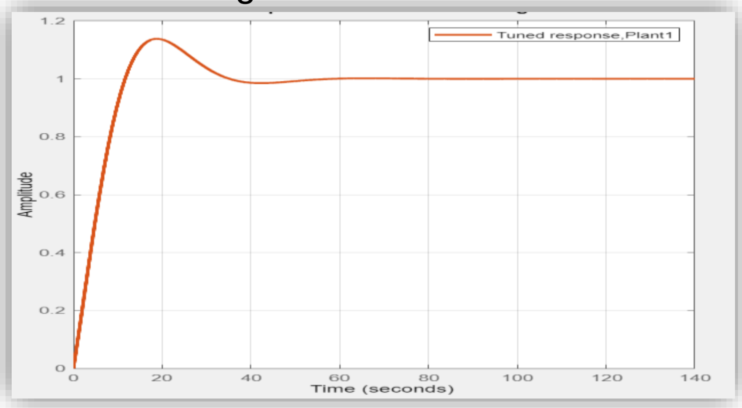


Fig3. For PI controller

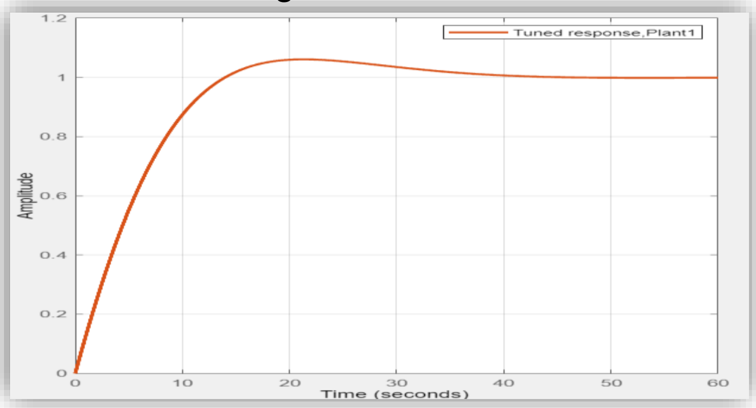


Fig4. For PID controller

Response after using P,I,PD and PID controller for Linear model for θ_2

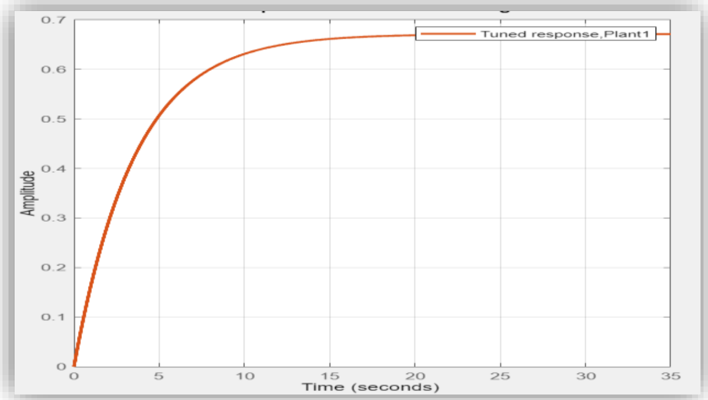


Fig2. For P controller

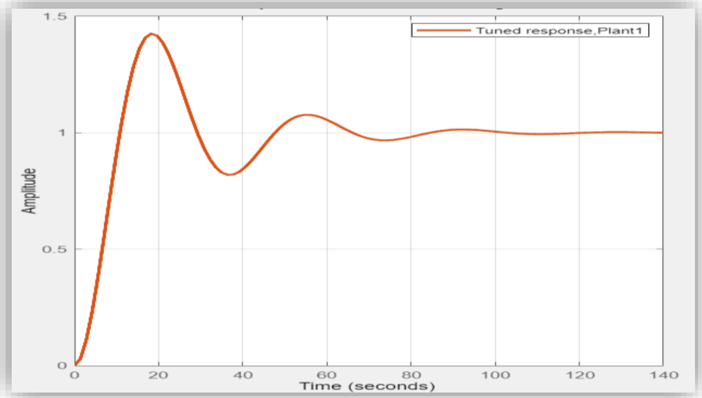


Fig1. For I controller

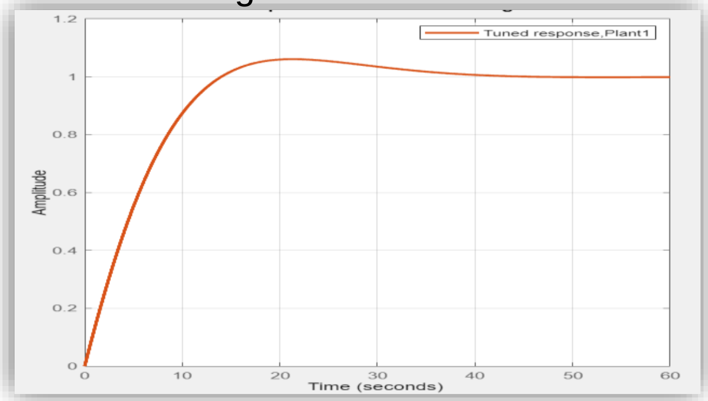


Fig4. For PID Controller

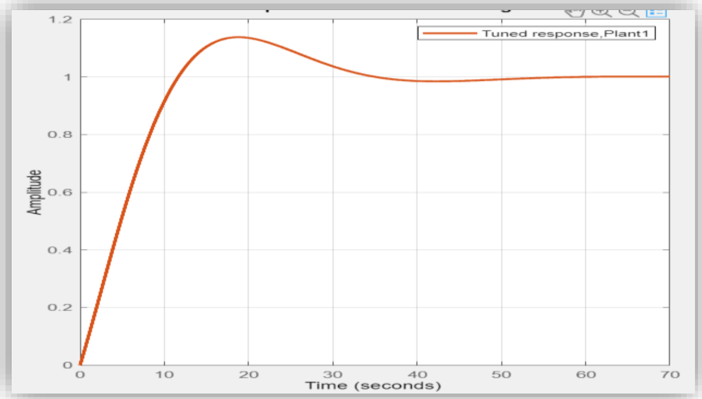


Fig3. For PI controller

Results from VRFT for non-linear model

Controller Type	K_p	K_i	K_d
PID(C 1)	-0.00800682	0.0172235	-0.01218325
PID(C 2)	-0.00117727	-0.00367201	0.00758266
PID(C 3)	-0.01140614	0.02433635	-0.0169803
PID(C 4)	-0.0153887	-0.00506457	0.01018464
PI(C 1)	-0.00351299	0.0041632	0
PI(C 2)	-0.0080388	-0.00874665	0
PI(C 3)	-0.00495979	-0.00595447	0
PI(C 4)	-0.01150534	0.0124133	0
P(C 1)	-0.00089219	0	0
P(C 2)	-0.00091696	0	0
P(C 3)	-0.00151058	0	0
P(C 4)	-0.00133139	0	0
I(C 1)	0	-0.00093575	0
I(C 2)	0	0.000094044	0
I(C 3)	0	-0.00158467	0
I(C 4)	0	0.00133139	0

Final Thoughts

- We learnt about the stabilization of pendulums using various controllers with VRFT and PID Tuning Algorithm.
- We simulated and observed the values of controller parameters obtained by VRFT method and PID Tuning Algorithm which makes the system stable.
- We plotted the results obtained after using the parameters provided by both of these methods for various systems like Simple Pendulum, Inverted Pendulum, Double Pendulum.
- The parameters differ in every of the cases, most of them tend to stabilize the system.

References

1.Code accessed from https://github.com/rssalessio/PythonVRFT/

2.MarcoC.Campi,SergioM.Savaresi,“DirectNonlinearControlDesign:TheVirtual ReferenceFeedbackTuning(VRFT)Approach”,IEEETRANSACTIONSONAUTOMATICCONTROL,VOL.51,NO. 1, JANUARY 2006

3.FabioPrevidi,MaurizioFerrarin,SergioM.Savaresi,SergioBittanti,“Closed-loopcontrolofFESsupportedstandingupandsittingdownusingVirtualReferenceFeedbackTuning”,ControlEngineeringPractice 13 (2005) 1173–1182

THANK YOU