Red Iberoamericana de Rehabilitación y Asistencia de Pacientes con Daño Neurológico mediante Exoesqueletos Robóticos de Bajo Coste - REASISTE

Classic Control for Exoskeletons

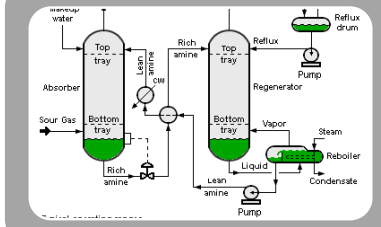
By: Rafael Mendoza Crespo

Presentation content

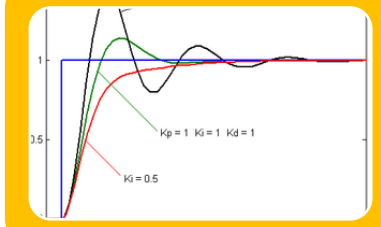
1. Introduction
2. Back to the Basics
3. Controller Improvements
4. Results
5. Conclusions

Introduction

Classic Control systems deals with the behavior of dynamical systems with inputs, and how their behavior is modified by feedback!



The usual objective of control theory is to control a system, often called the *plant or process*, so its output follows a desired control signal, called the *reference*, which may be a fixed or changing value.



A *controller* is designed, in order to monitor the output and compares it with the reference. The difference between actual and desired output, called the *error* signal.

Error Signal is applied as feedback to the input of the system, to bring the actual output closer to the reference.

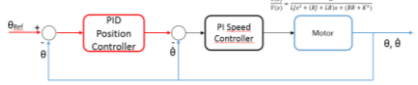
Introduction

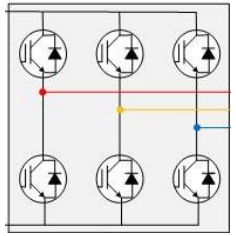
Classic Control by Excelence!

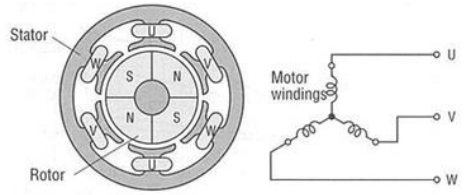
PID Controller

Proportional Integral Derivative Controller

Standard Digital Implementation







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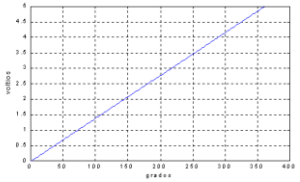
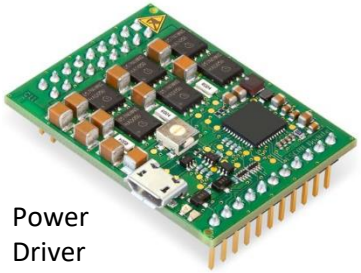
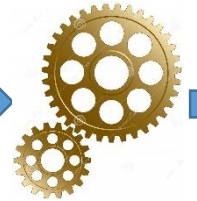


Microcontroller



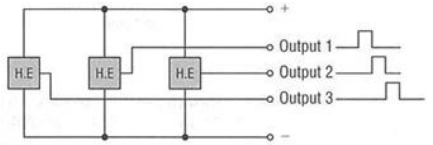
Power
Driver

Brushless
Motor



Mechanical
Reduction
GearBox
Harmonic Drive

Variable Resistor
Encoder



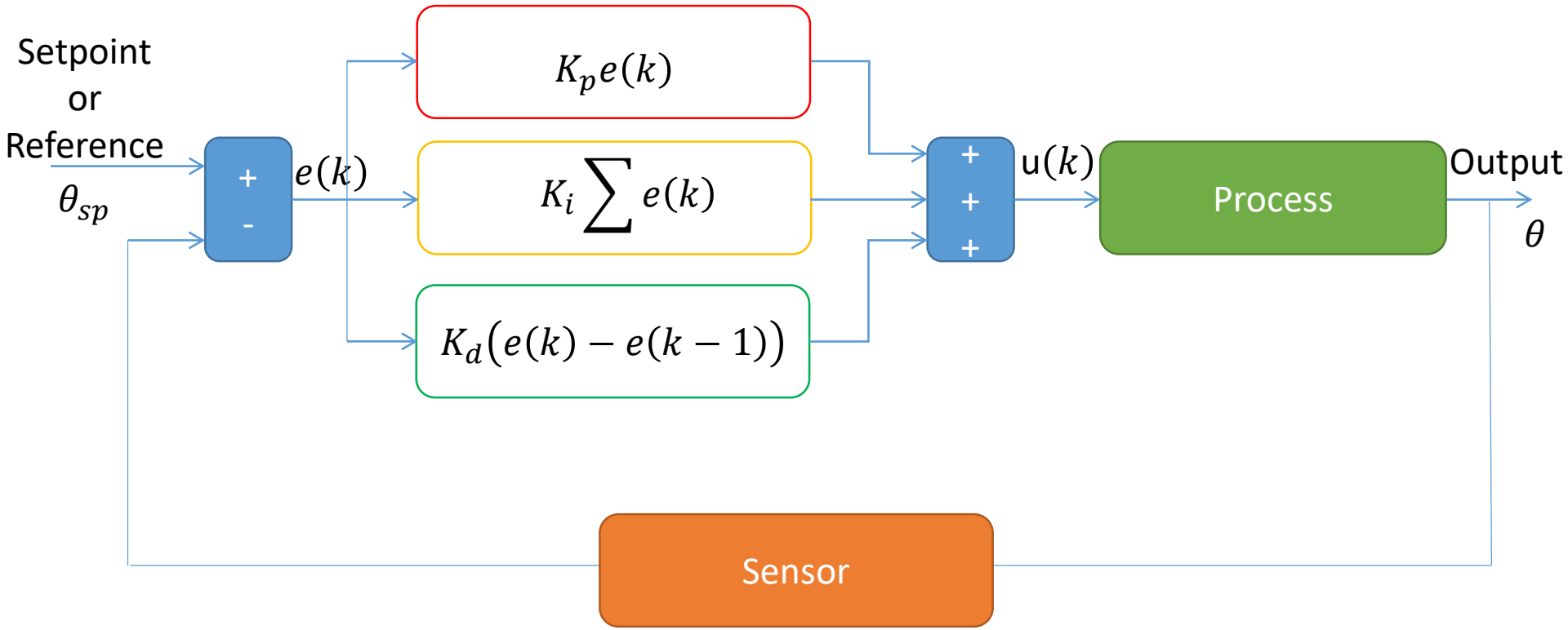
Hall effect Sensors

Speed Control Loop

Position Control Loop

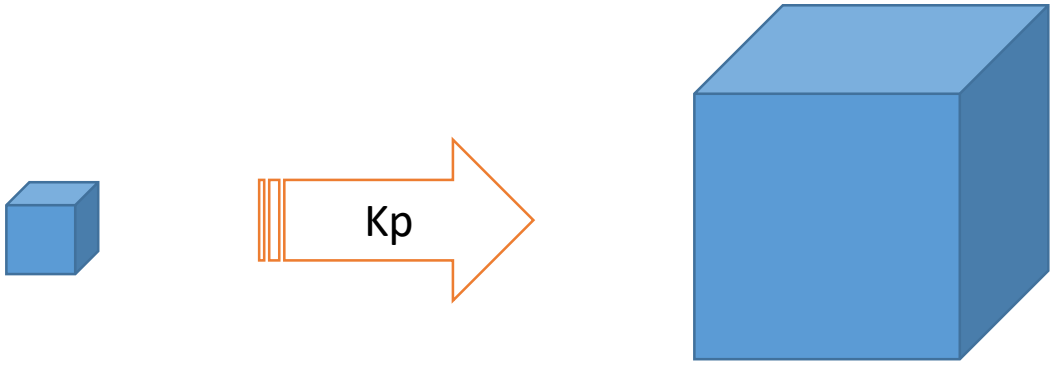
Proportional Integral Derivative Controller

Standard Digital Implementation



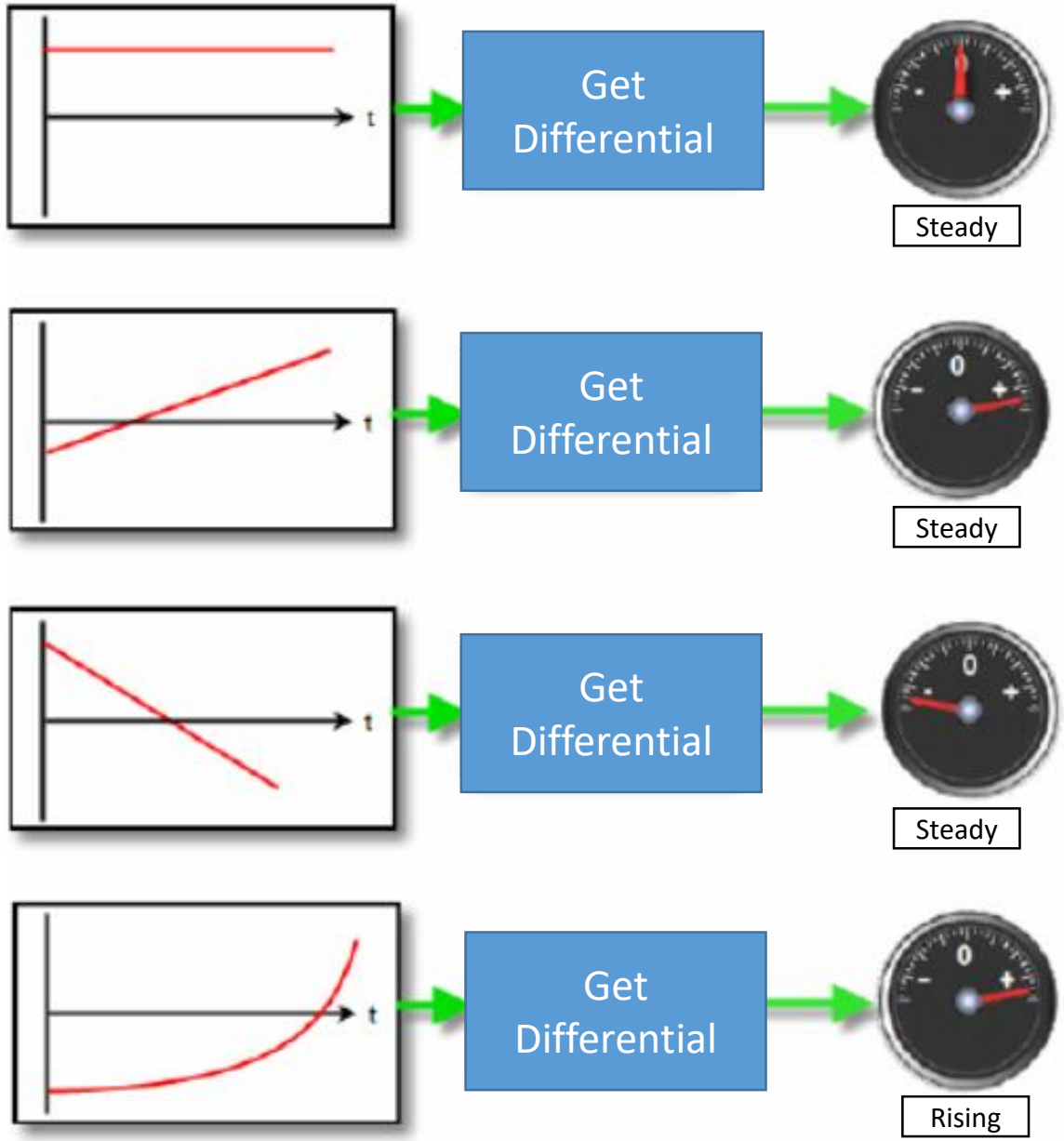
Back to the Basics

Porportional Gain



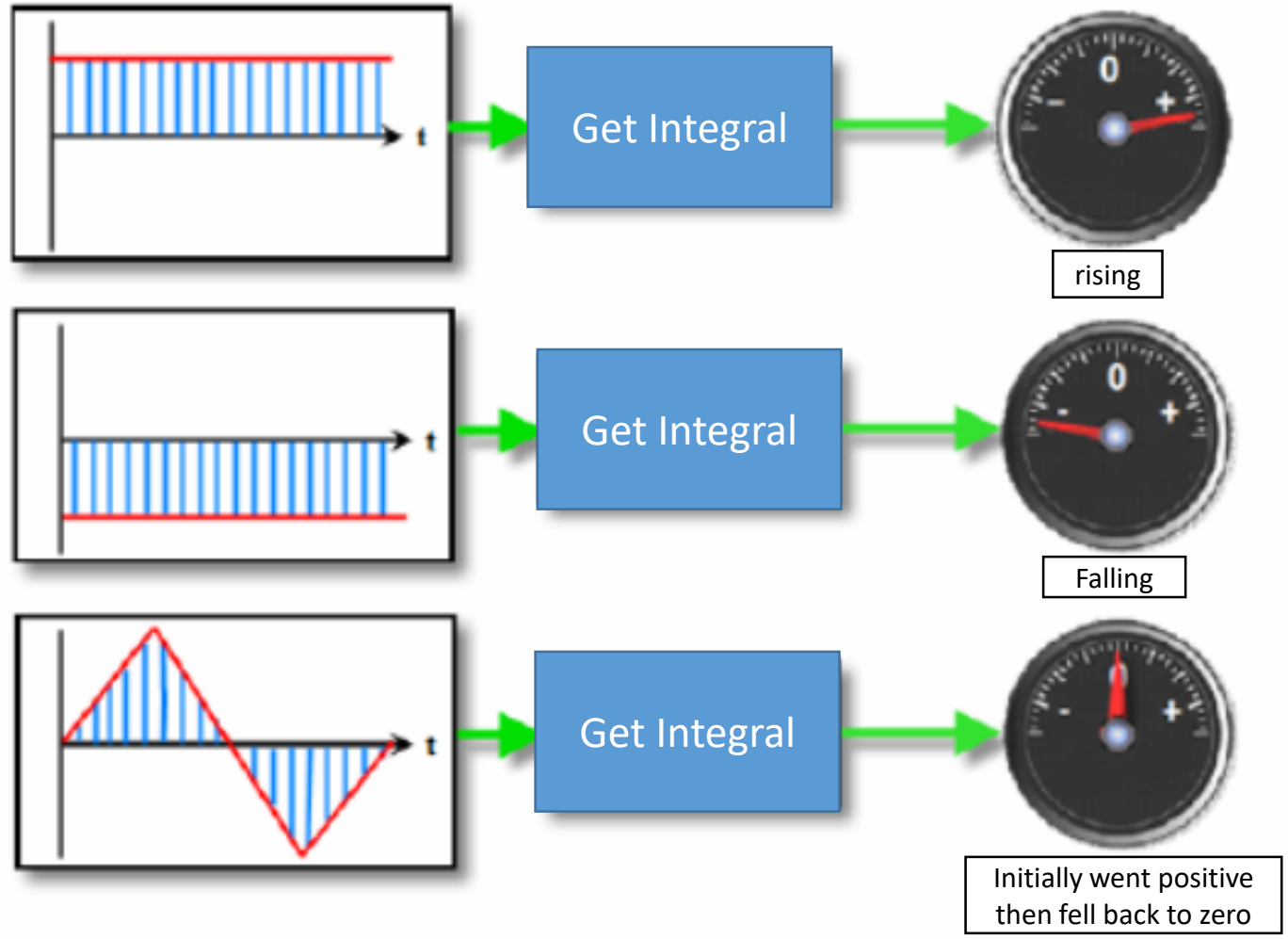
Back to the Basics

Derivative Gain

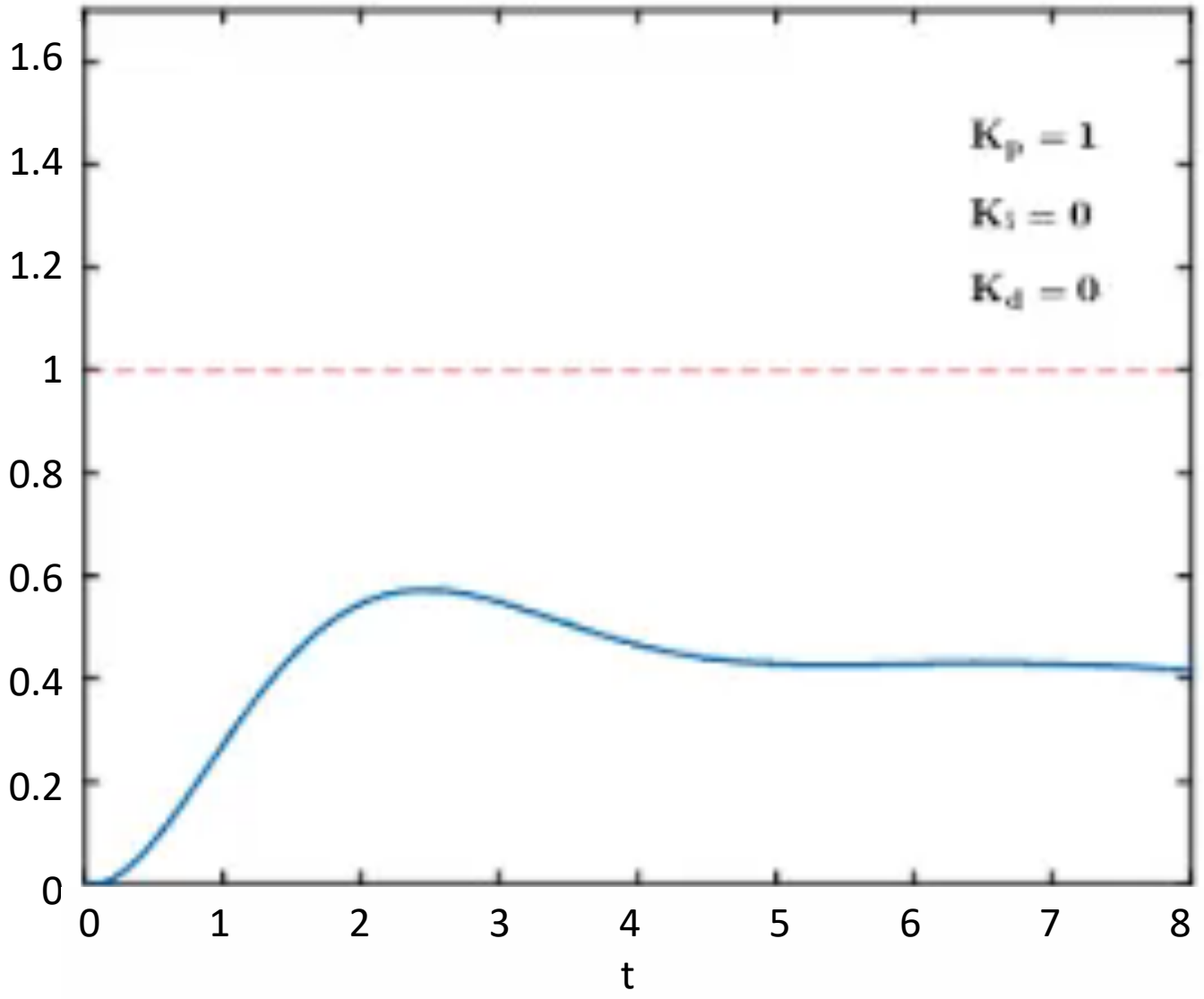


Back to the Basics

Integral Gain



Back to the Basics



Proportional Integral Derivative Controller

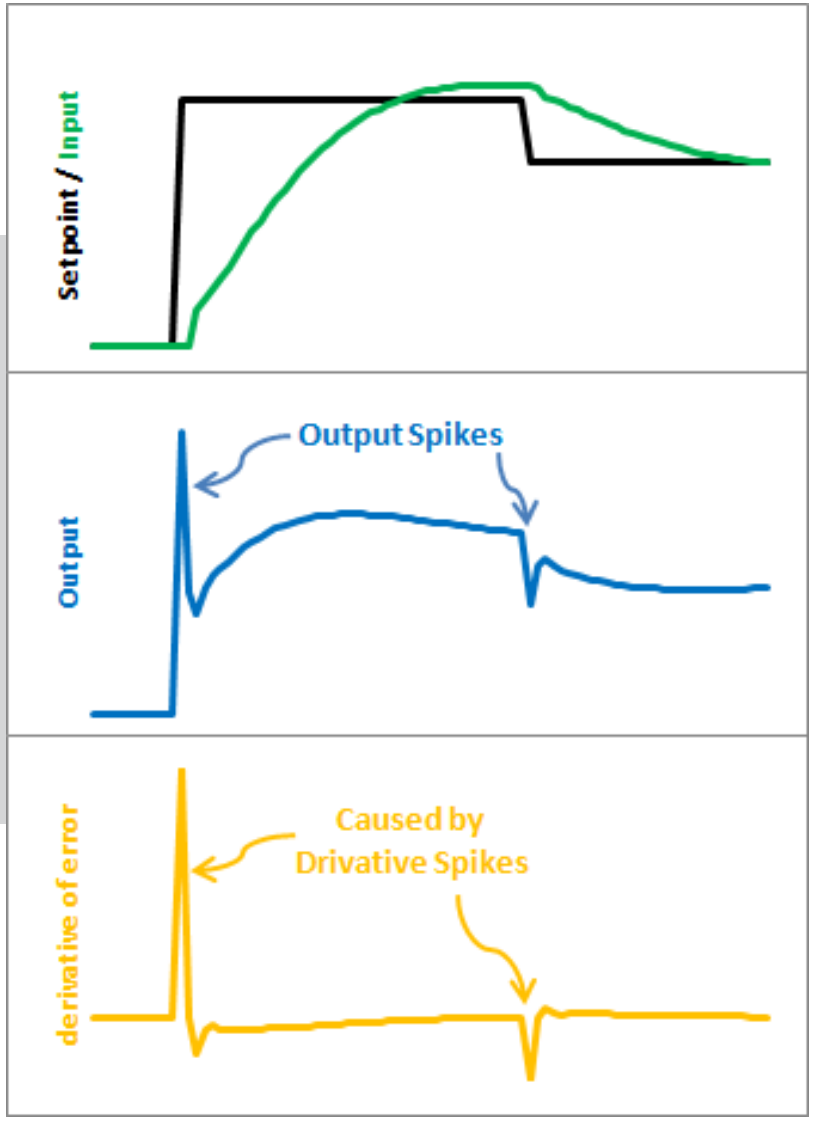
Digital Implementation Improvements

1. **Derivative Kick**
2. **On-The-Fly Tuning Changes**
3. **Reset Windup Mitigation**
4. **On/Off (Auto/Manual)**
5. **Initialization**

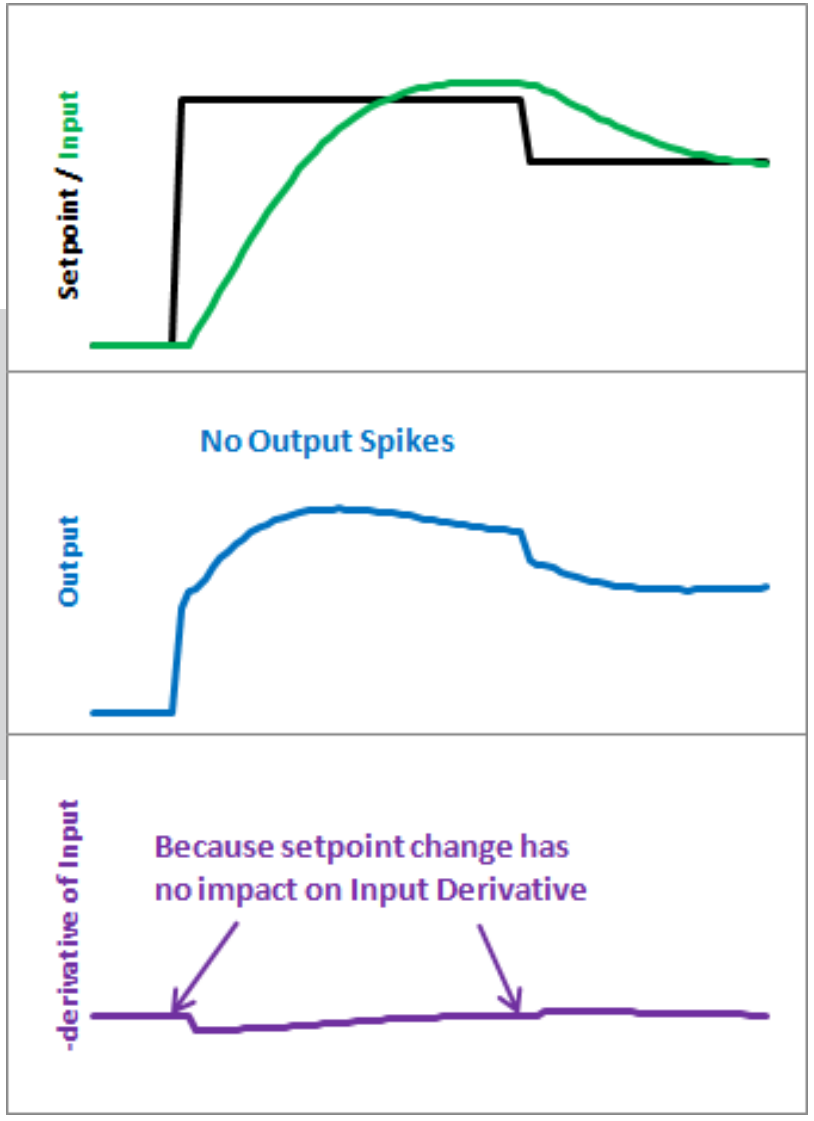
Proportional Integral Derivative Controller

Digital Implementation Improvements - Derivative Kick

The Problem



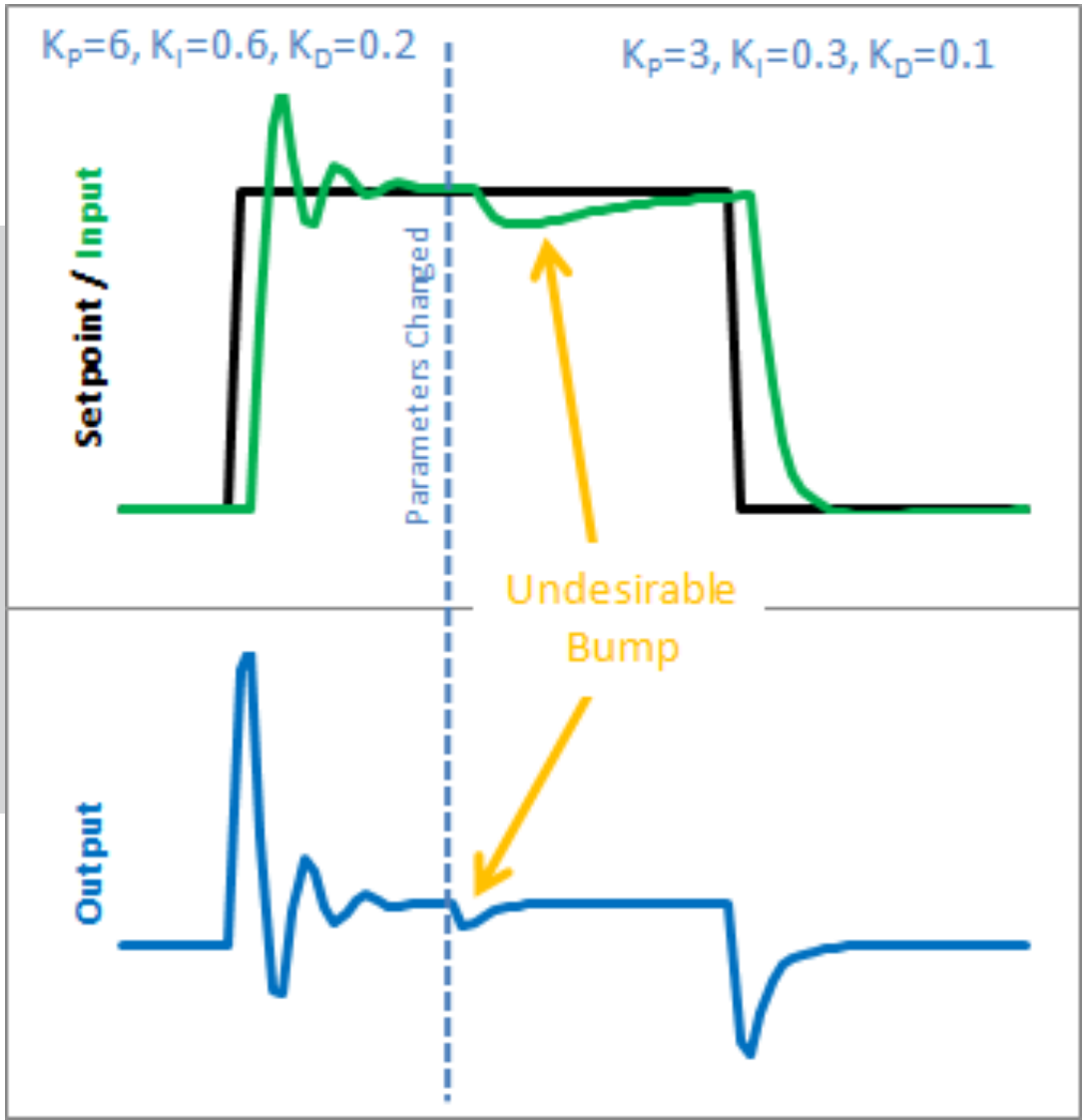
The Result



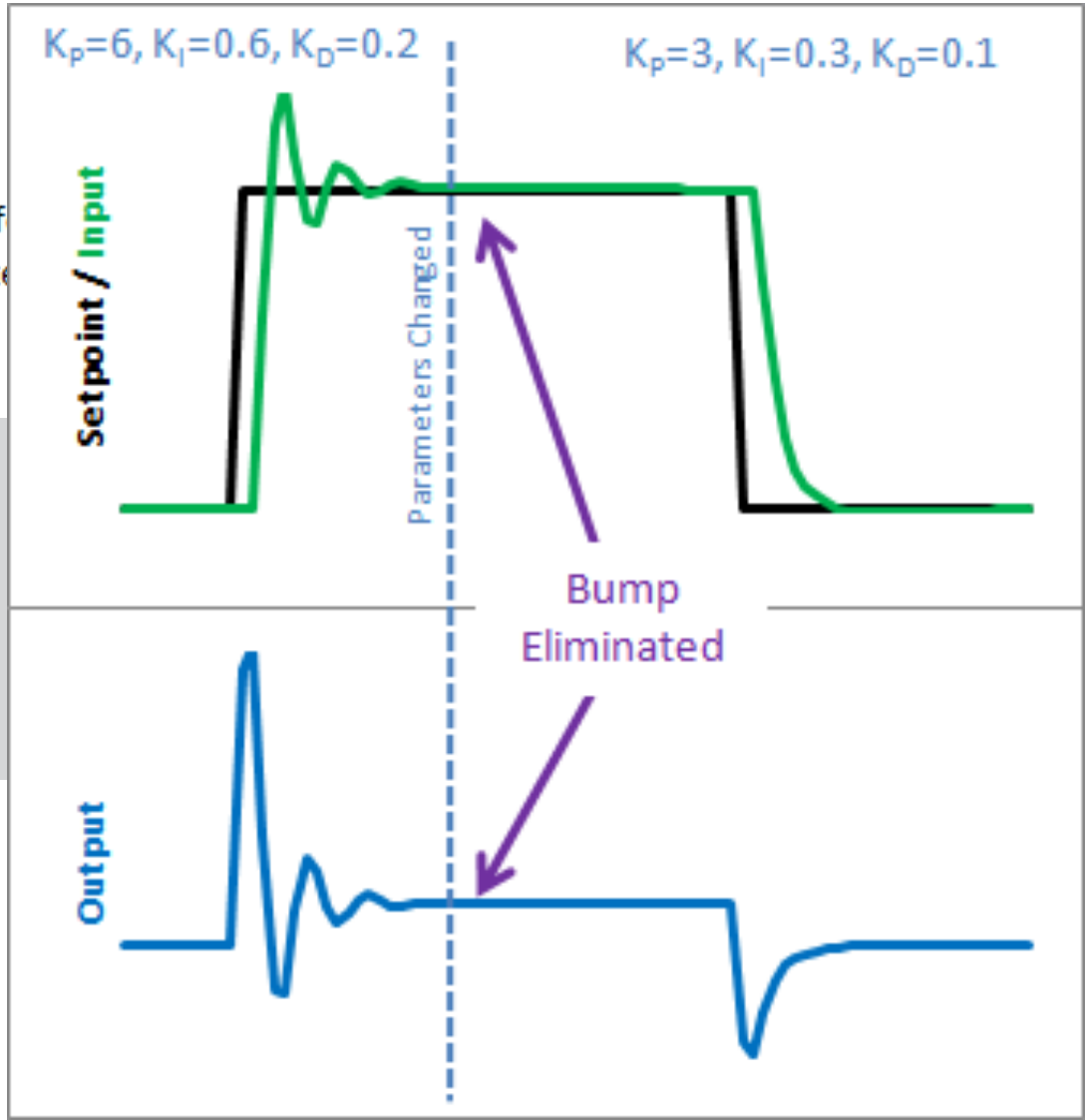
Proportional Integral Derivative Controller

Digital Implementation Improvements – On the fly tuning changes

The Problem



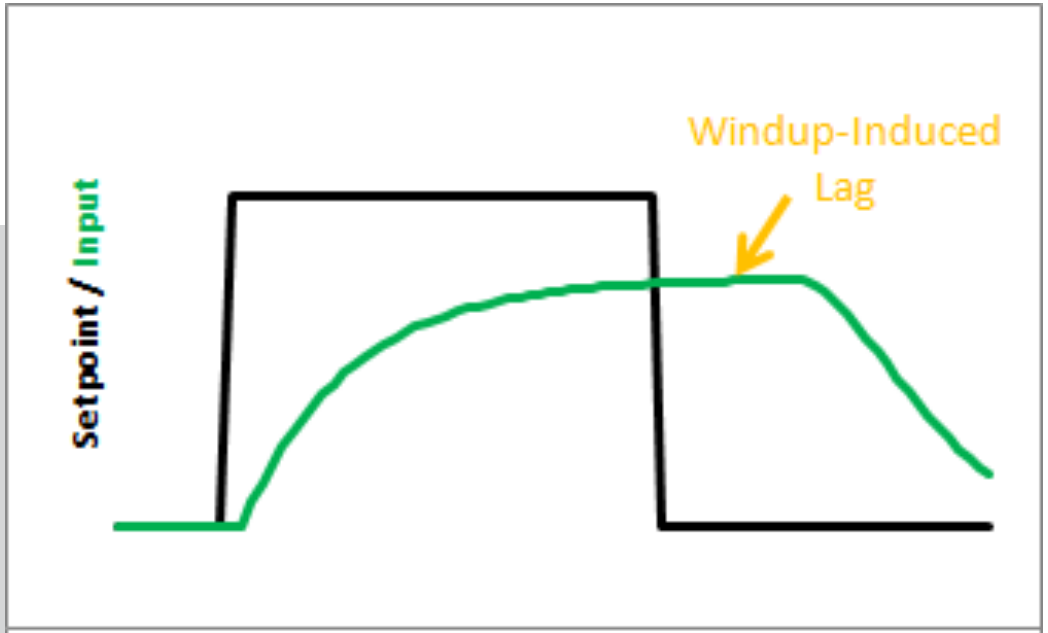
The Resu

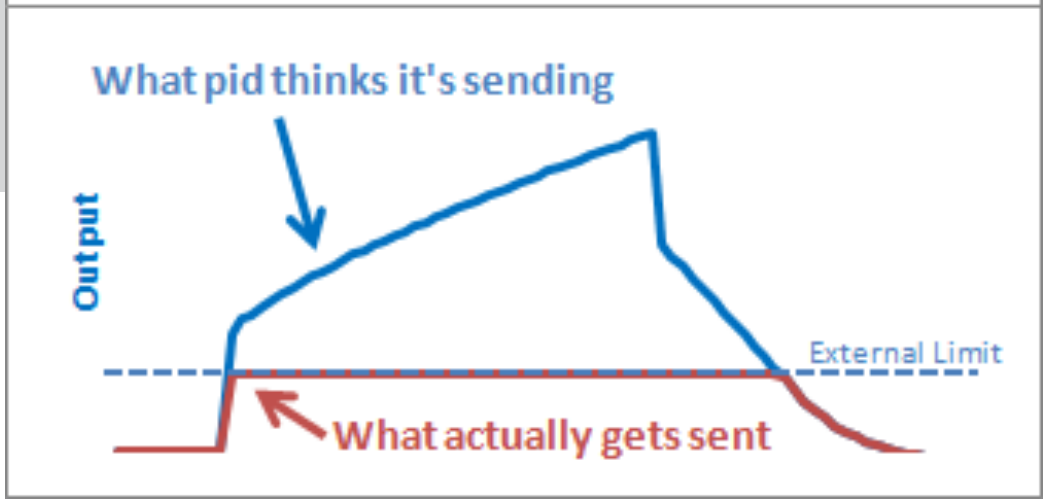


Proportional Integral Derivative Controller

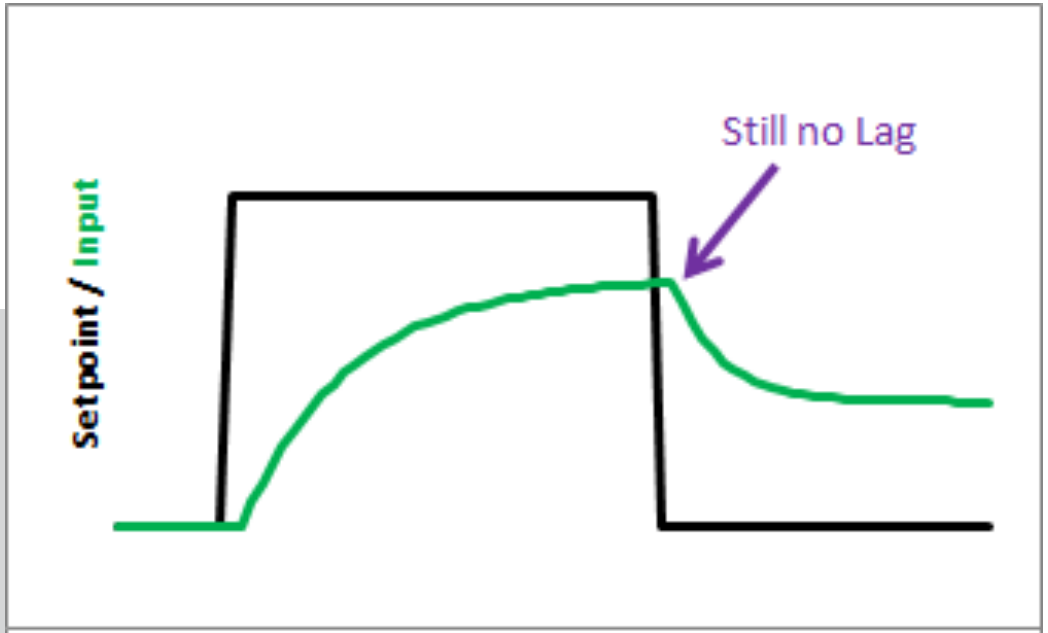
Digital Implementation Improvements – Windup Reset

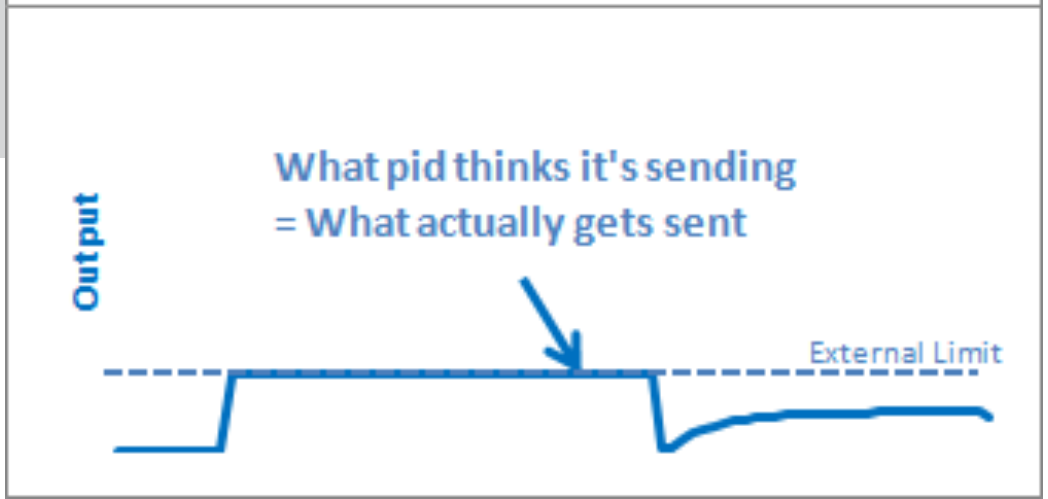
The Problem





The Result

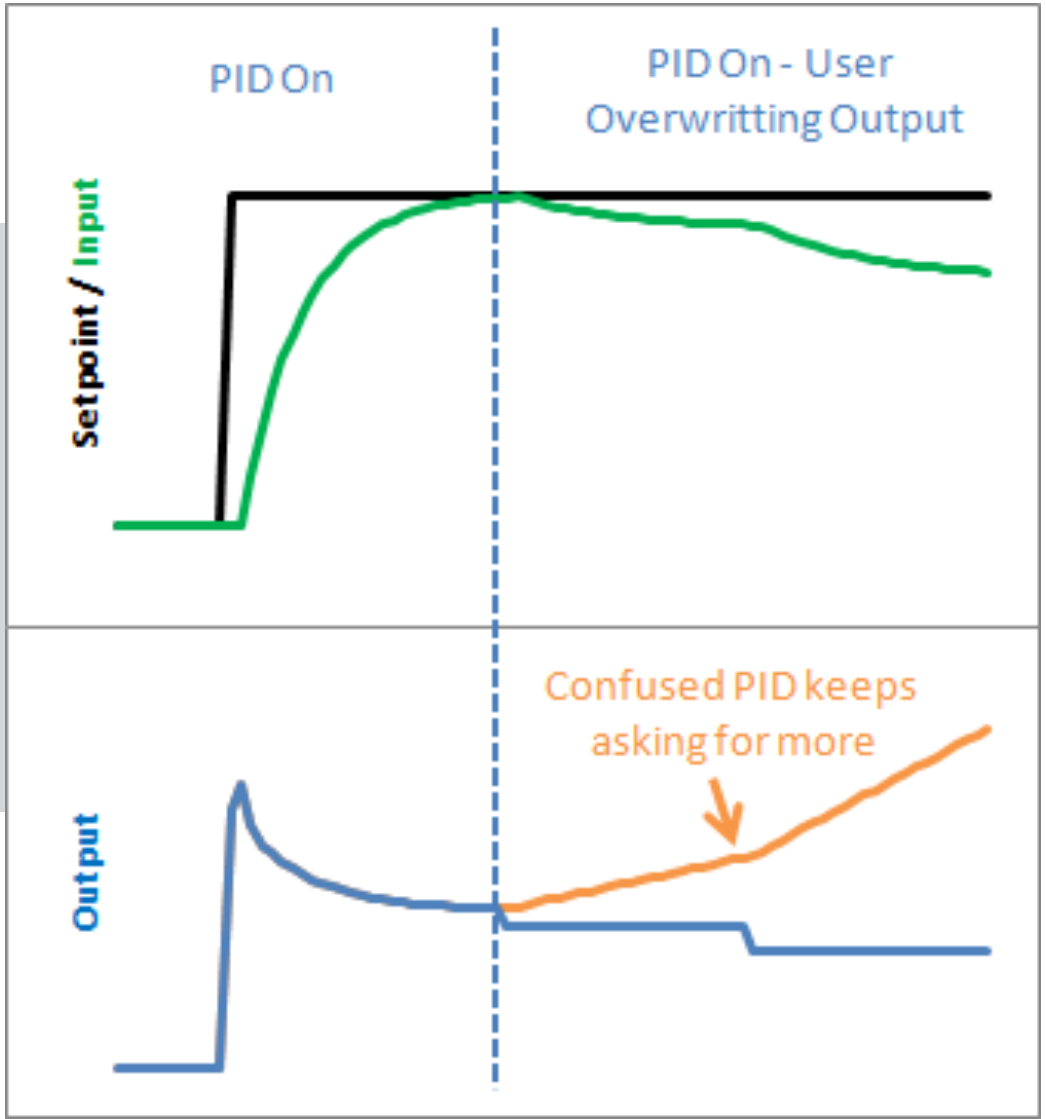




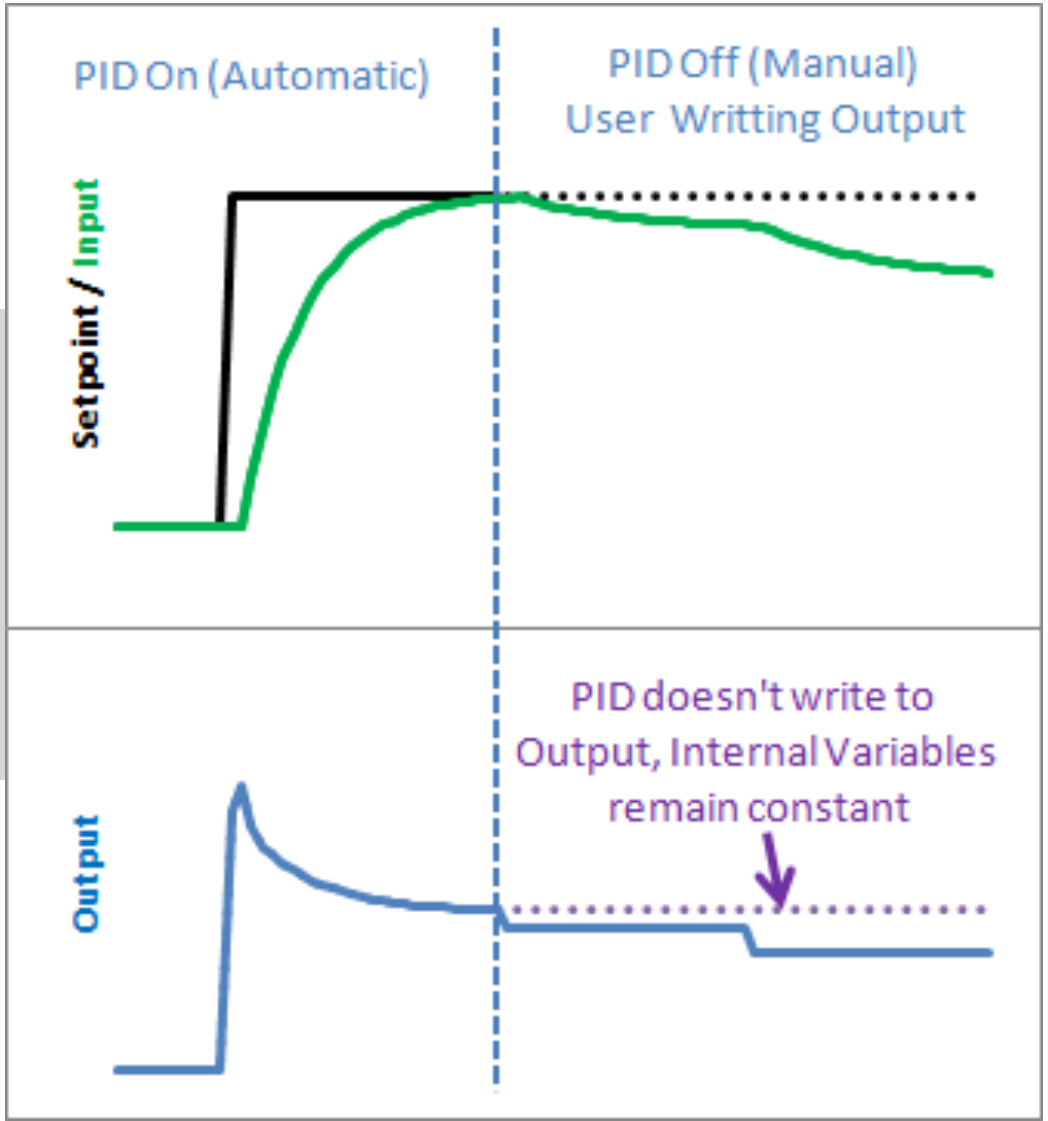
Proportional Integral Derivative Controller

Digital Implementation Improvements – PID Controller On/Off

The Problem



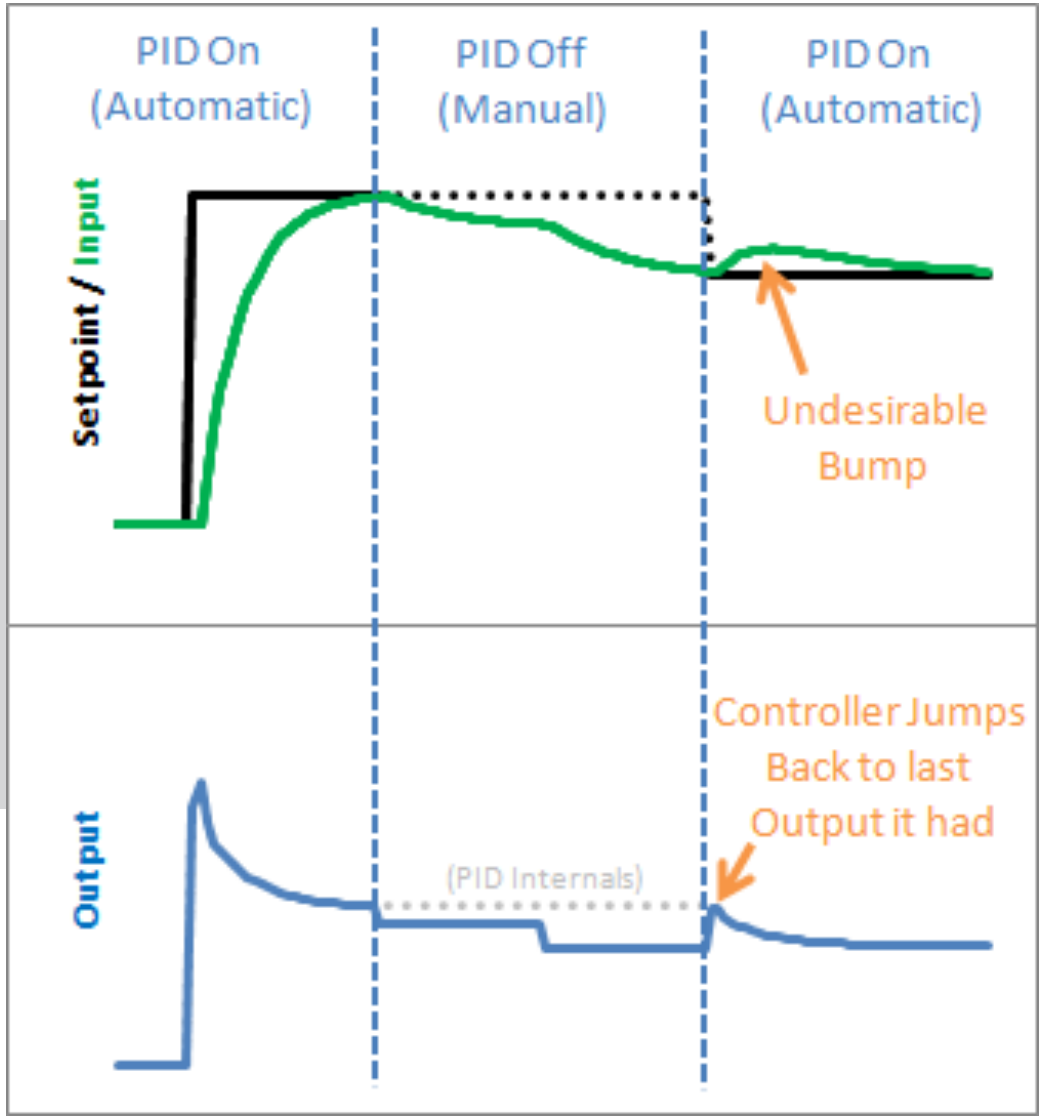
The Result



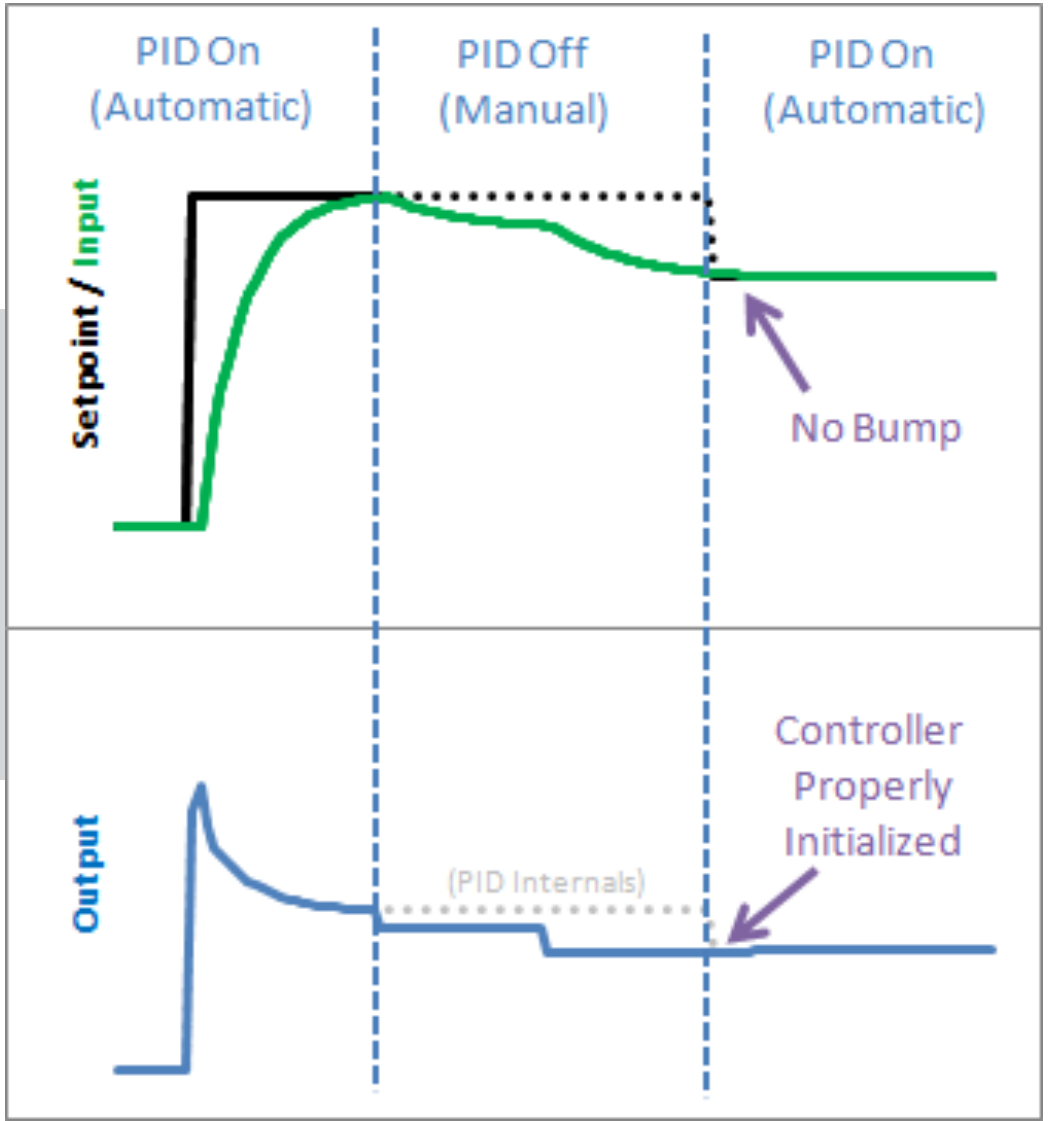
Proportional Integral Derivative Controller

Digital Implementation Improvements – Initialization Manual to Auto

The Problem



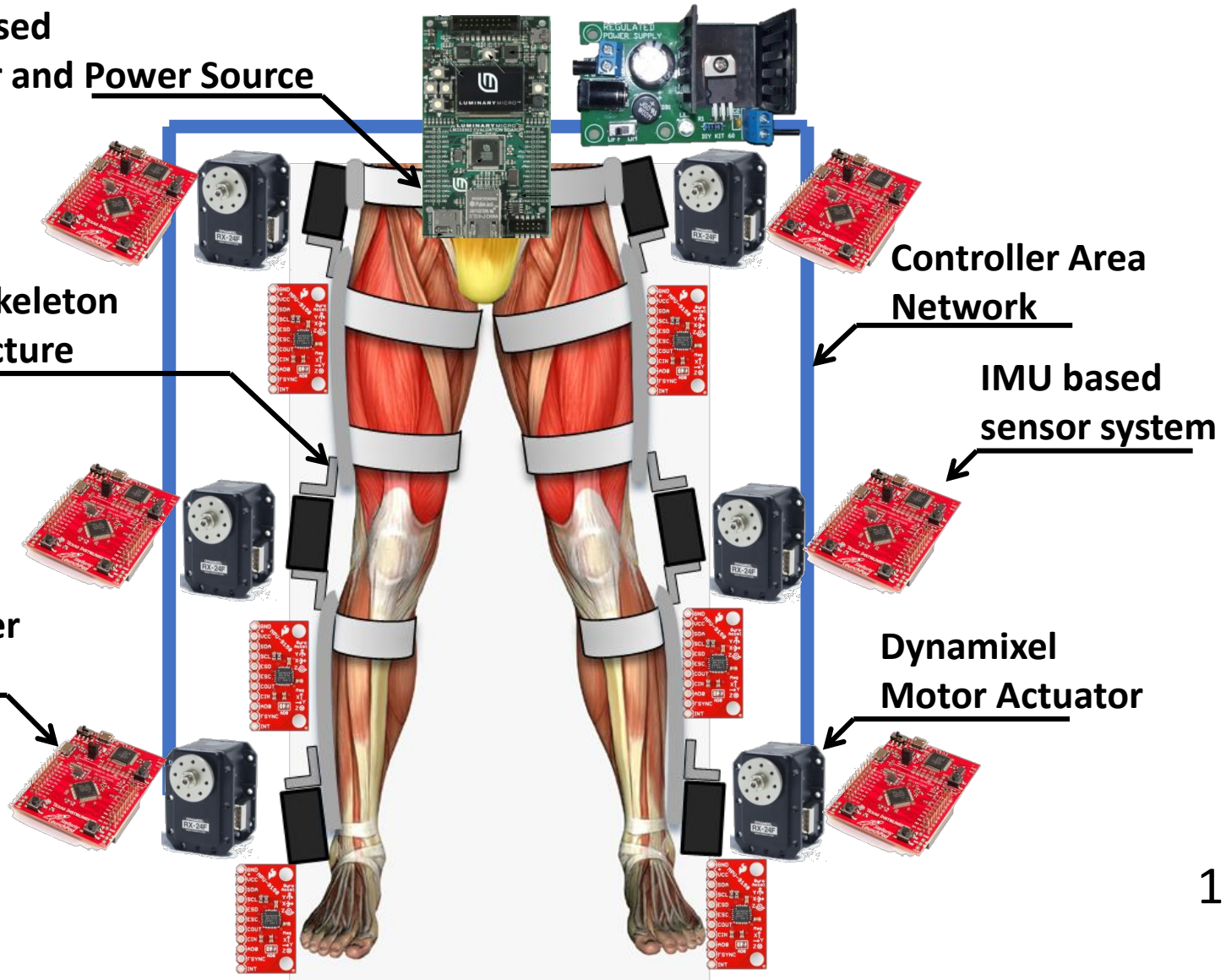
The Result



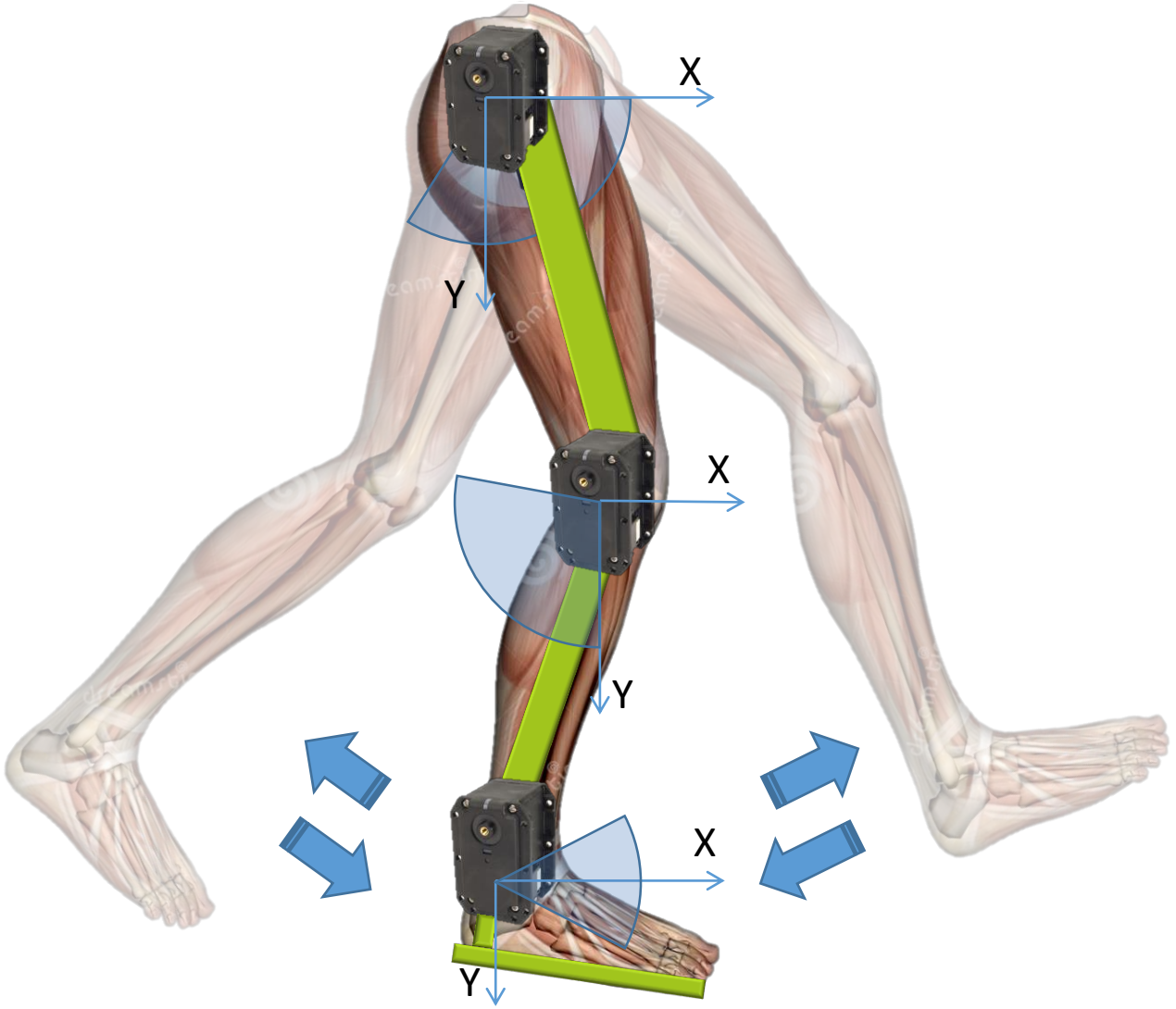
Complete system description

T1

Exoskeleton

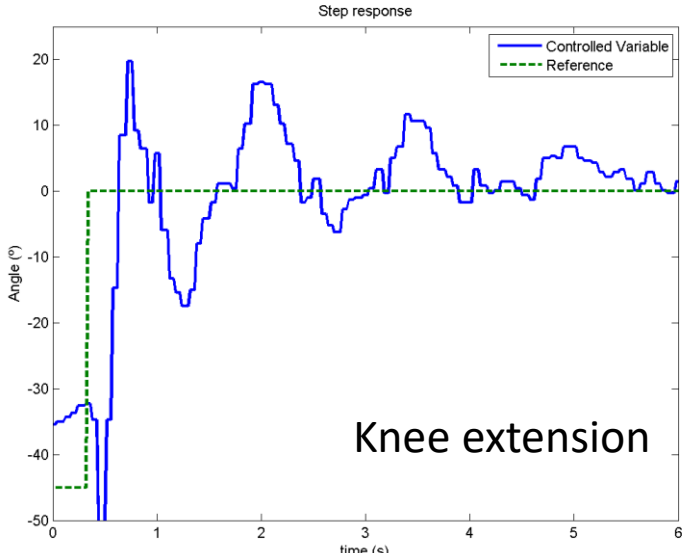


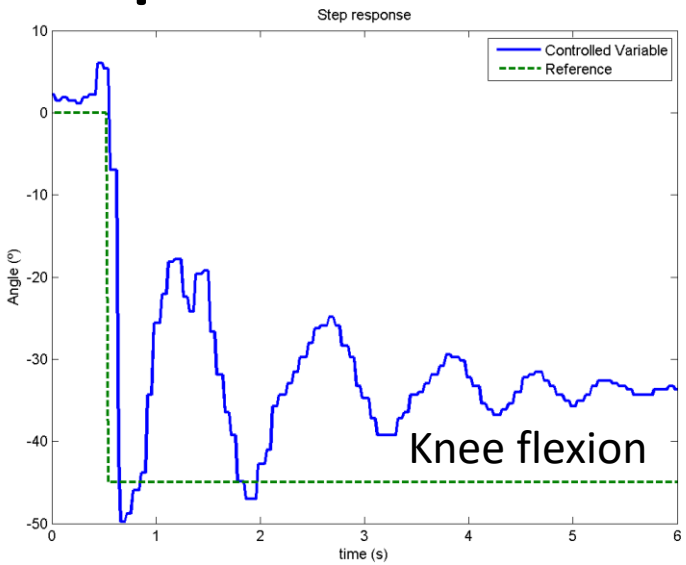
System Identification

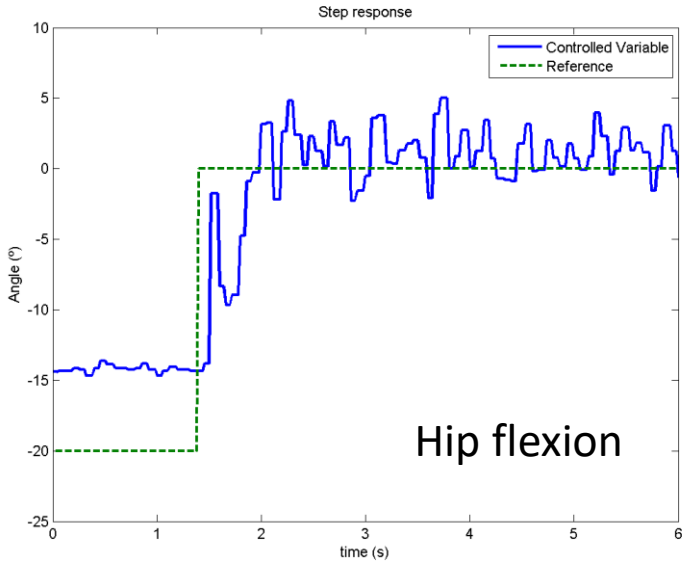


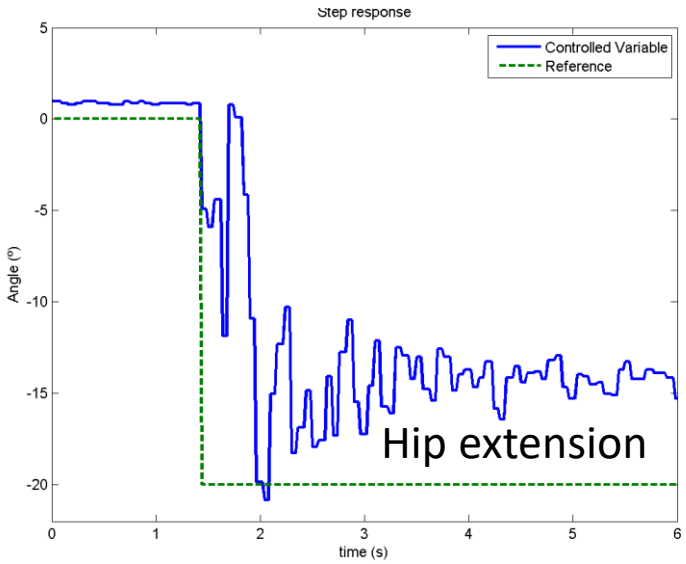
Sagittal Plane

System Identification: Step Response

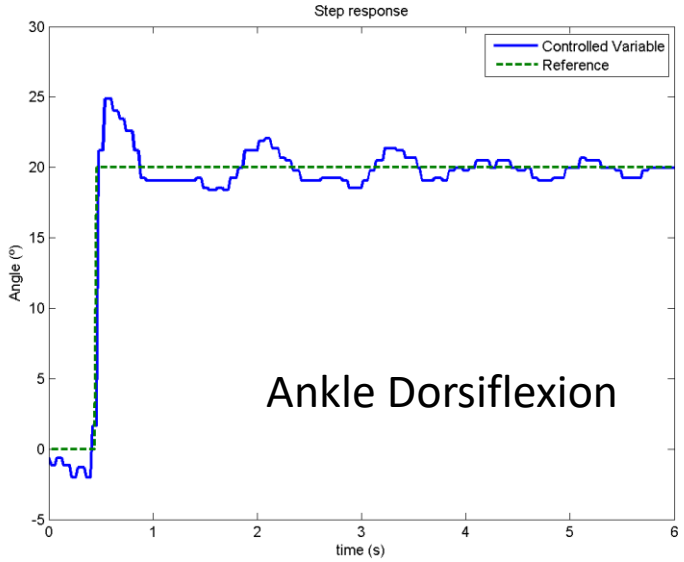


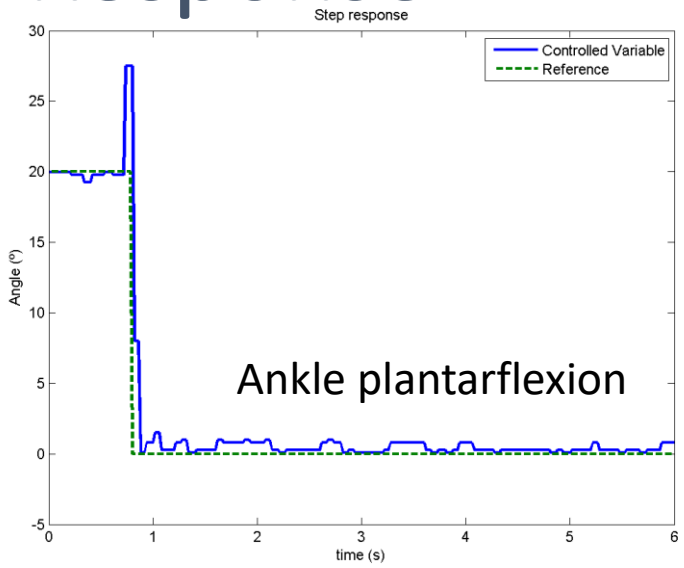


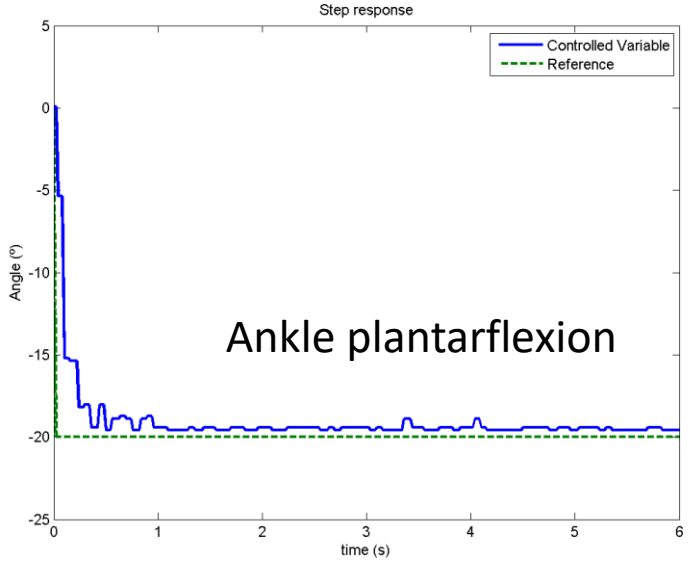


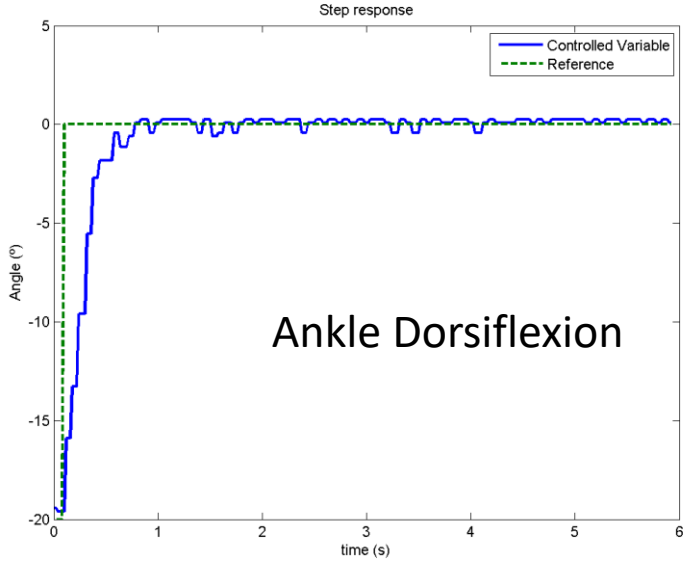


System Identification: Step Response









Transfer Functions

System identification transfer functions

$\frac{Y(s)}{U(s)} = \frac{0.7677}{(8.52s+1)(8.51s+1)}$ (3.2)	$\frac{Y(s)}{U(s)} = \frac{0.7802}{(8.00s+1)(7.96s+1)}$ (3.3)
$\frac{Y(s)}{U(s)} = \frac{0.7915e^{-0.09s}}{(0.30s+1)(0.3166s+1)}$ (3.4)	$\frac{Y(s)}{U(s)} = \frac{0.8379e^{-0.05s}}{(0.7771s+1)(0.7771s+1)}$ (3.5)
$\frac{Y(s)}{U(s)} = \frac{1.03e^{-0.043s}}{(0.7776s+1)(0.0409s+1)}$ (3.6)	$\frac{Y(s)}{U(s)} = \frac{0.9796}{(1.86s+1)(0.60s+1)}$ (3.7)
$\frac{Y(s)}{U(s)} = \frac{0.9773e^{-0.0448s}}{(4.52s+1)(0.5s+1)}$ (3.8)	$\frac{Y(s)}{U(s)} = \frac{0.9775e^{-0.0233s}}{(7.16s+1)(3.0s+1)}$ (3.9)

3.2, 3.3 Hip extension, flexion

3.4, 3.5 Knee flexion, extension

3.6, 3.9 Ankle dorsiflexion

3.7, 3.8 Ankle extension

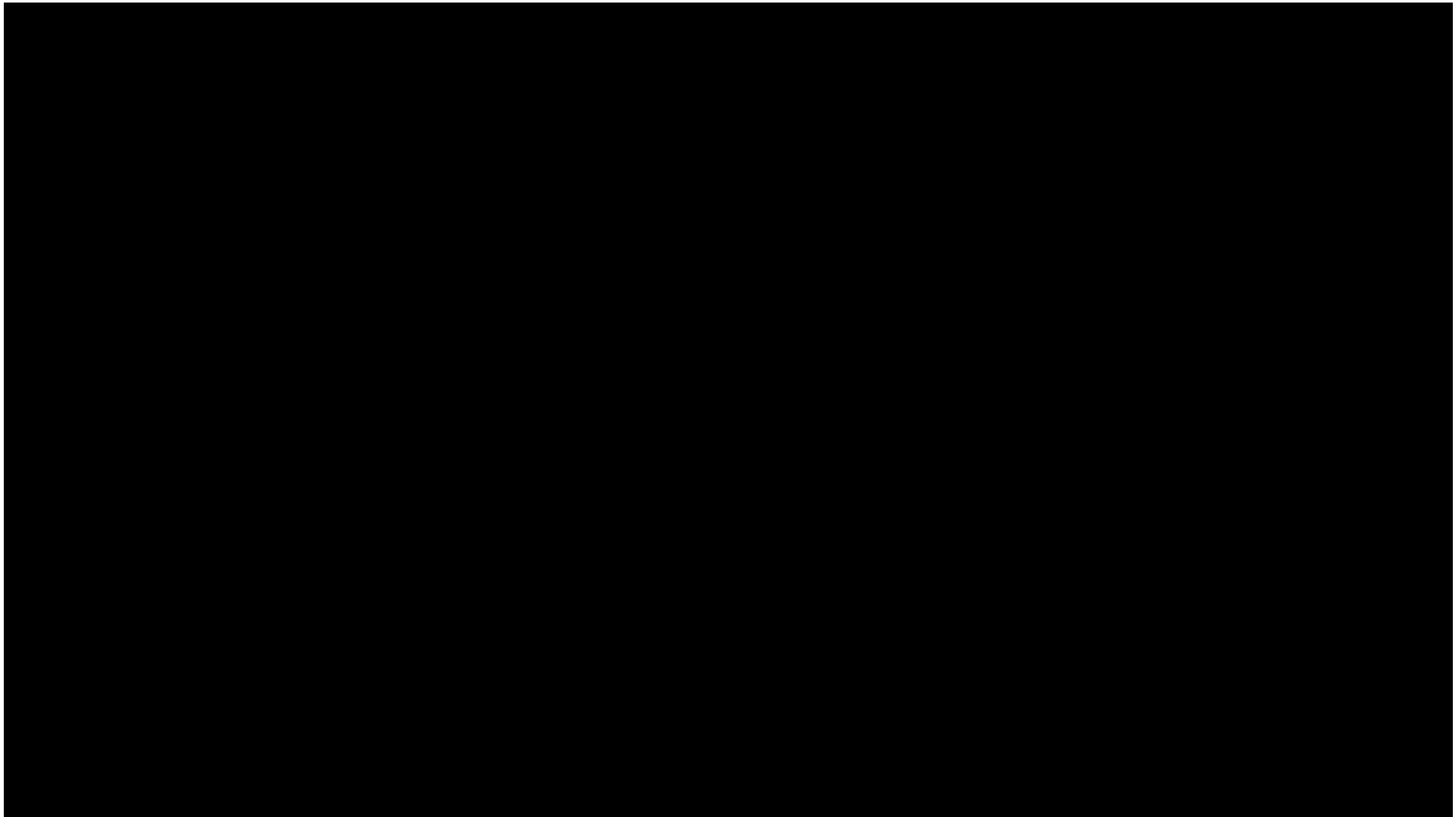
Control system fidelity

Fi Hip	Fi Knee	Fi Ankle
91.45%	89.67%	96.67%

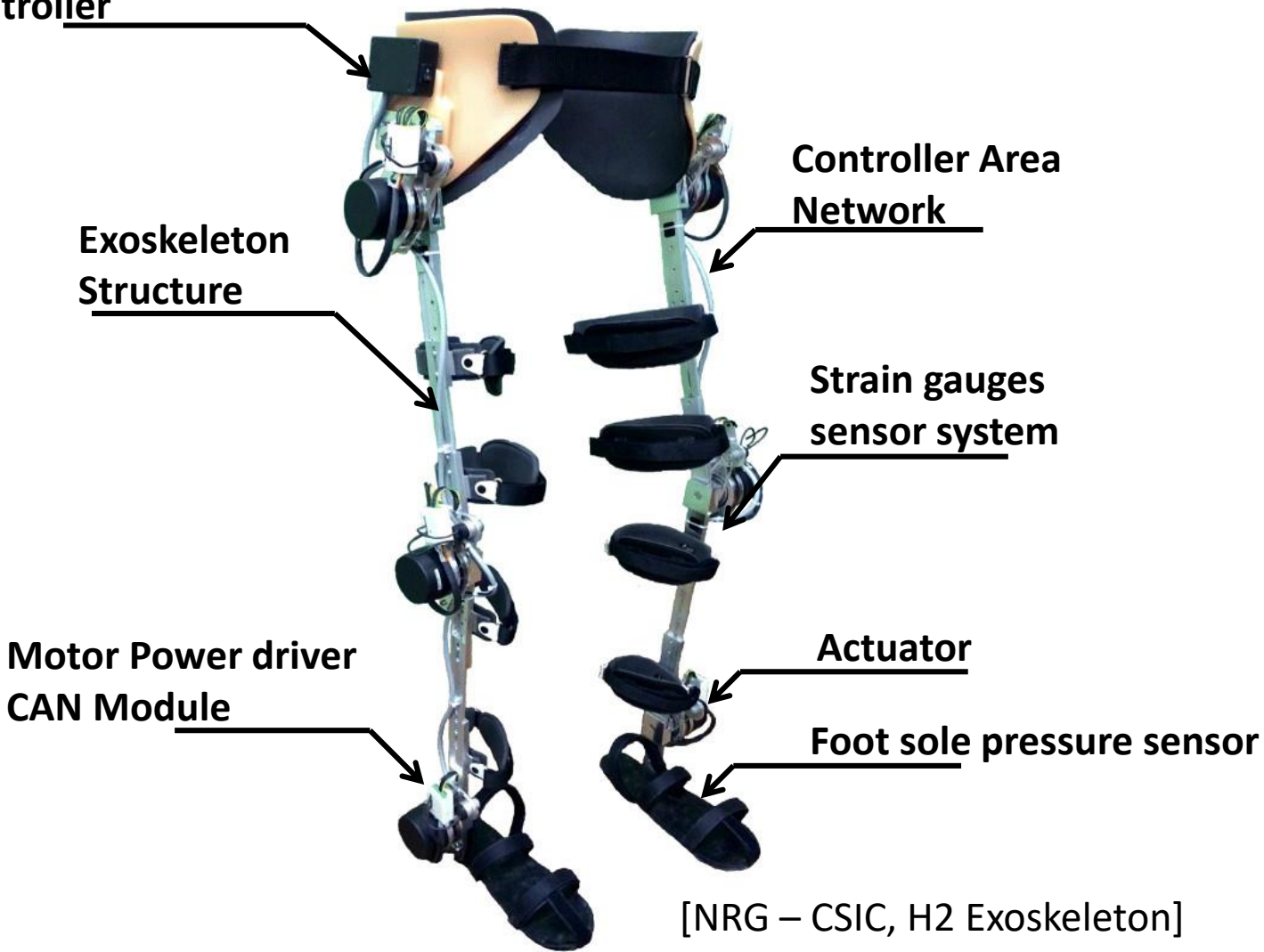
$$Fidelity = \left(1 - \frac{var\left(\theta_{output} - \theta_{sp}\right)}{var\left(\theta_{output}\right)}\right)$$

[Cherelle, 2010]

P. Cherelle, V. Grosu, P. Beyl, A. Mathys, R. V. Ham, M. V. Damme, B. Vanderborght, and D. Lefeber, "The MACCEPA actuation system as torque actuator in the gait rehabilitation robot ALTACRO," Biomedical Robotics and Biomechatronics (BioRob), 2010 3rd IEEE RAS and EMBS International Conference on, 2010.



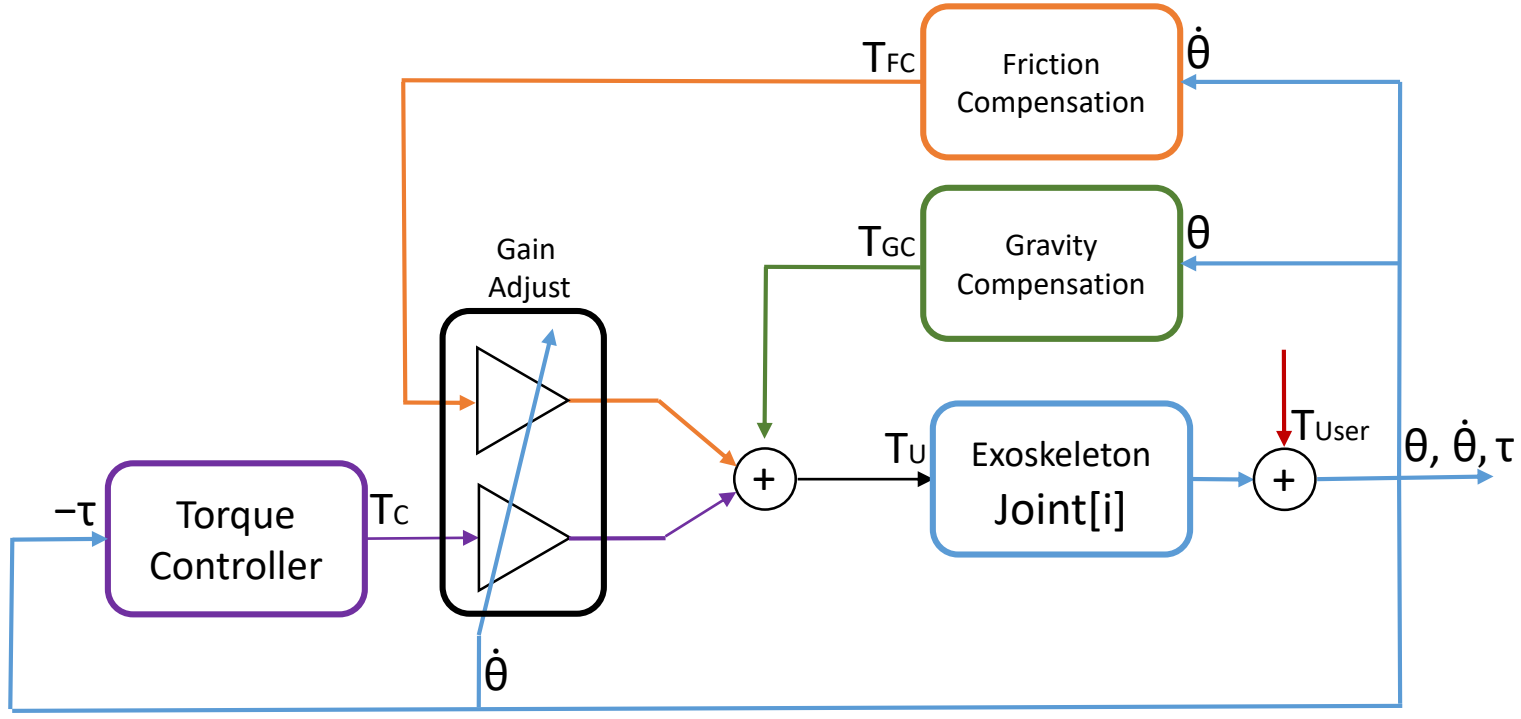
Experimental Setup



[NRG – CSIC, H2 Exoskeleton]

Experimental Setup

Transparent Mode Control System Block Diagram

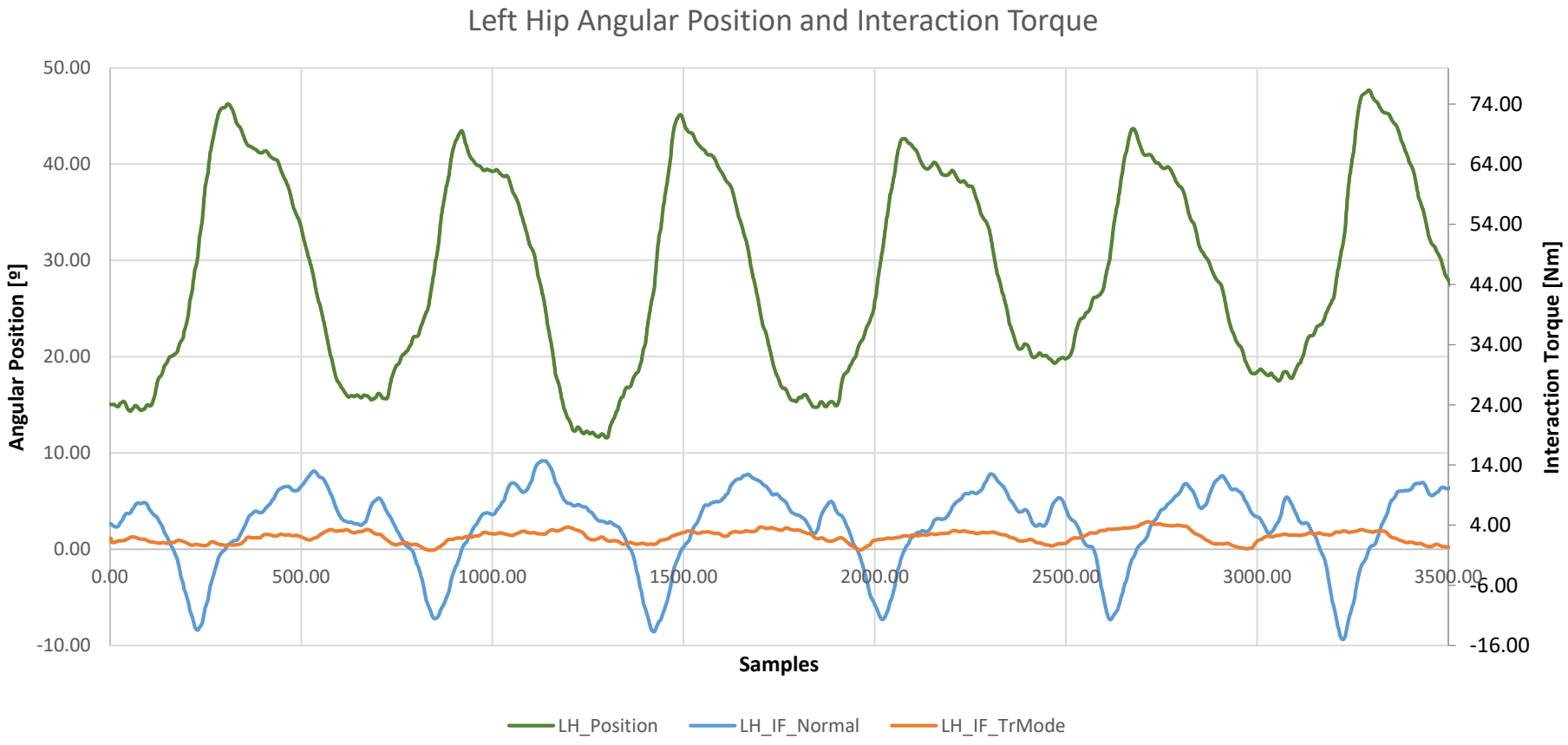


Θ Joint Angular Displacement
Tc Controller Torque
TFG Friction and Gravity compensation Torque
Tu Torque command

[R. Mendoza-Crespo, et al, "Transparent Mode for Lower Limb Exoskeleton," (WeRob), 2016.]

Experimental Setup

Transparent Mode Control System Block Diagram

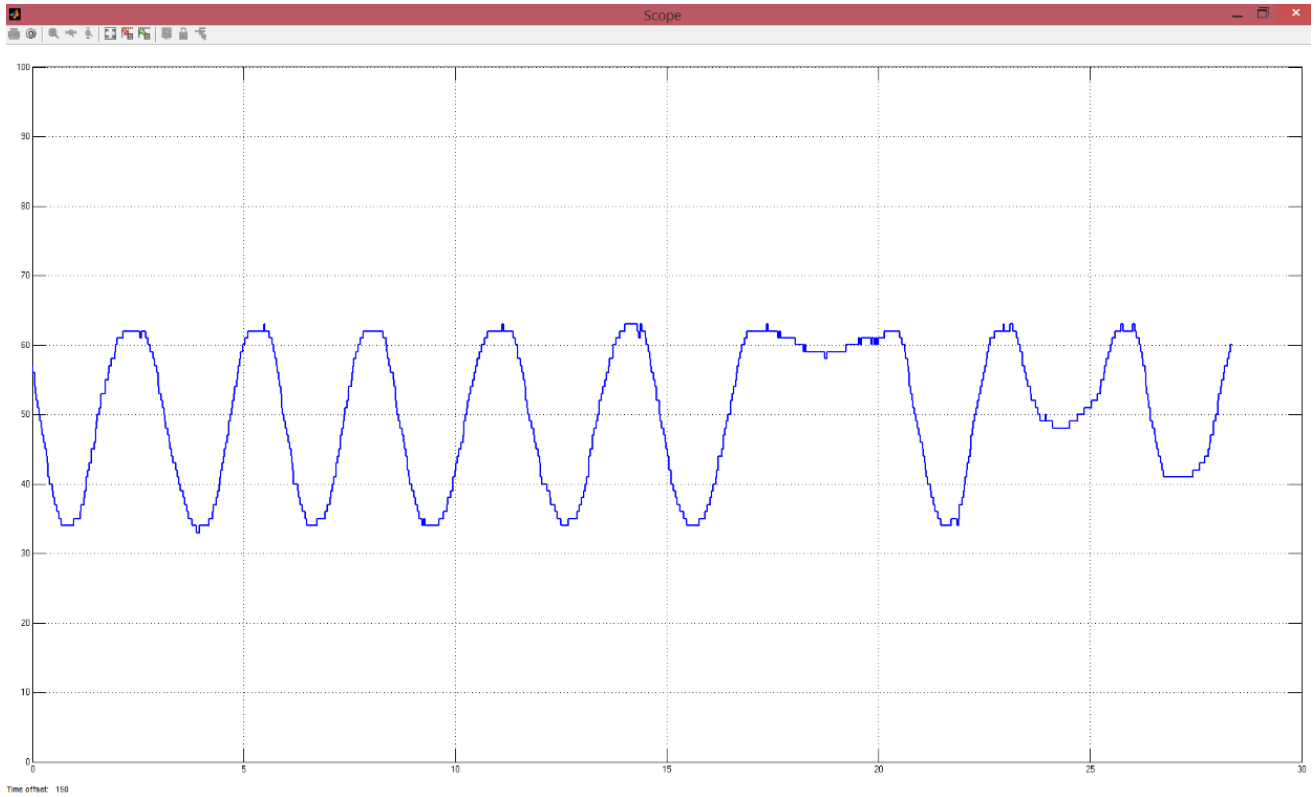


[R. Mendoza-Crespo, et al, "Transparent Mode for Lower Limb Exoskeleton," (WeRob), 2016.]

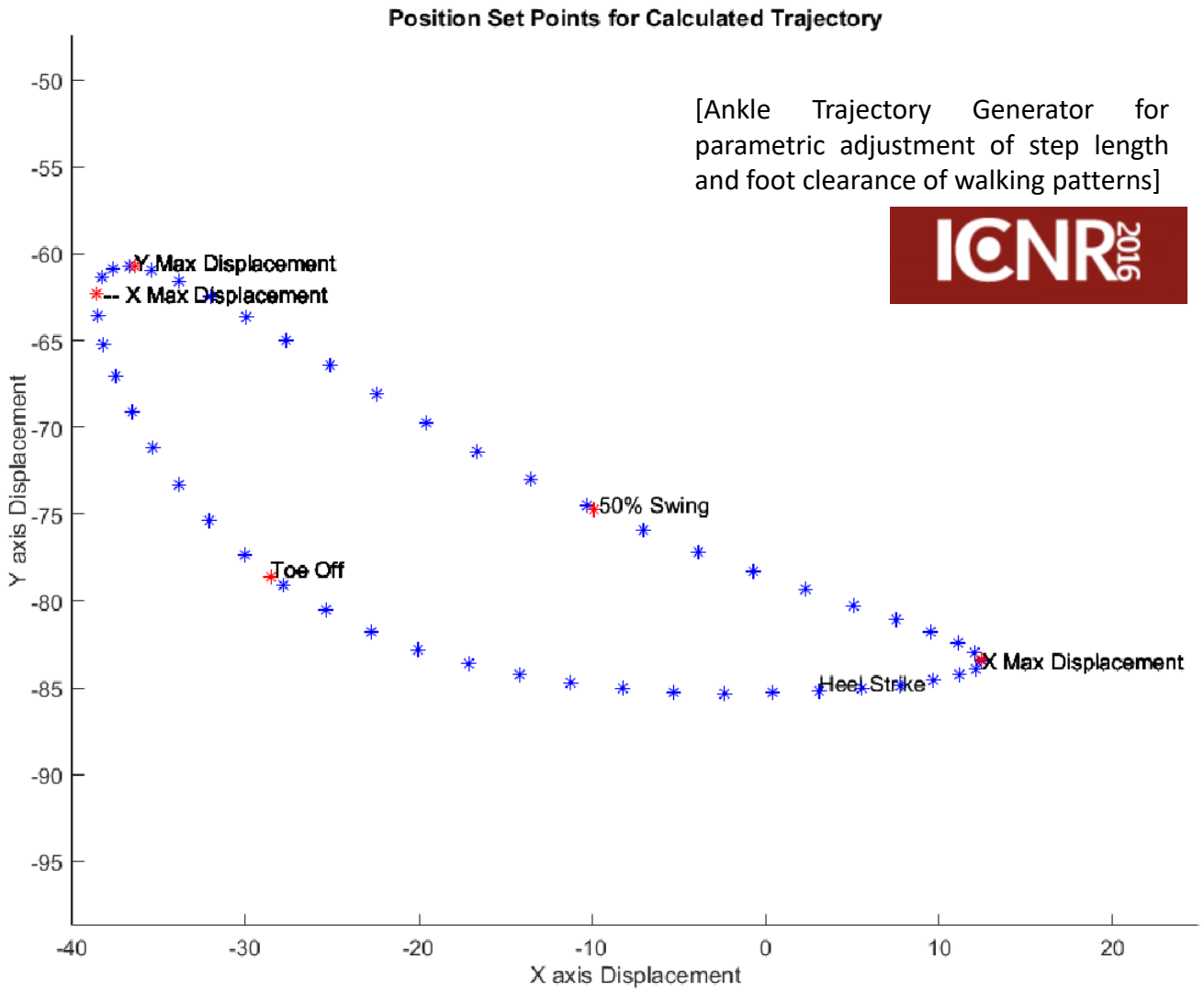
Friction compensation + stiffness + damping

SP = 45
K = 1 Stiffness Constant
Bd = 0.5 Damping Constant

Sine signal input Response + Torque Limit



Trajectory generator trials



[Ankle Trajectory Generator for parametric adjustment of step length and foot clearance of walking patterns]

ICNR 2016

Conclusions

PID Controllers are still a very good tool for some process.

PID Controllers and its modifications are able to control some nonlinear process.

Several PID Control Loops can be implemented in a very low power microcontrollers.

Position Control implemented for each exoskeleton joints allow us to track walking patters very precisely

Thanks for your attention

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Bolivia

te espera

México