Introduction

Control and Robotics in Medicine

Departamento de Tecnología Fotónica y Bioingeniería
Universidad Politécnica de Madrid

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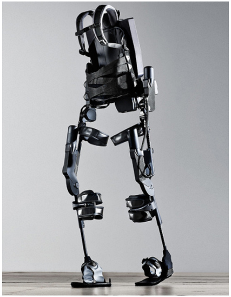
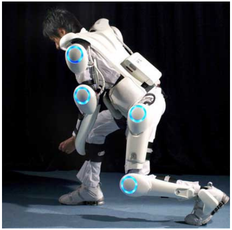
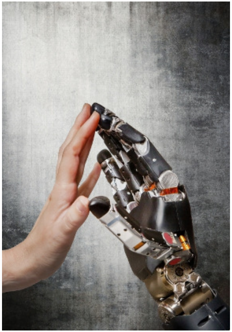
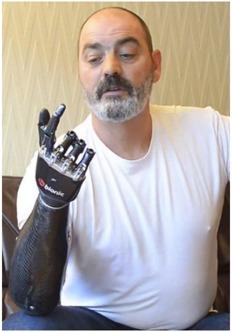
Orthoses



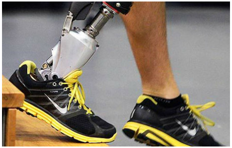


Prostheses

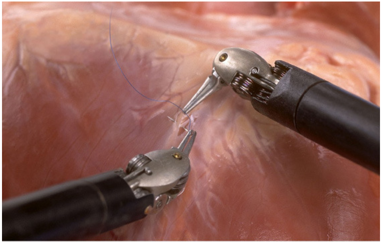








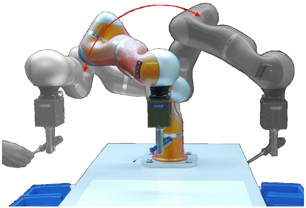
Telesurgery

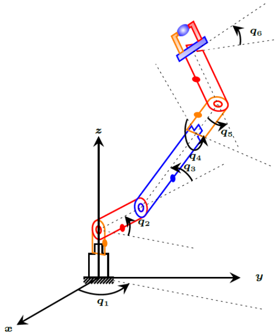


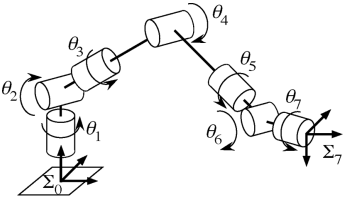
Contents

Mechanics

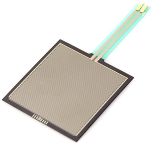
- Mechanic structures
- Forward and inverse kinematics
- Forward and inverse dynamics
- Trajectory planning

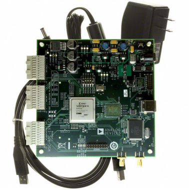


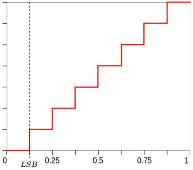




Sensors

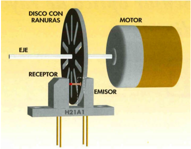




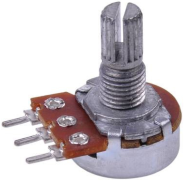


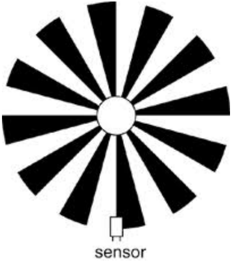
Sensors

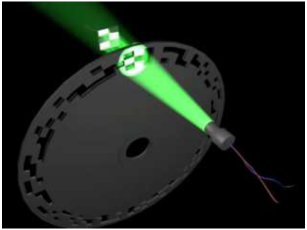
- Magnetic
- Optical
- Acoustic
- Inertial
- Mechanical



Position



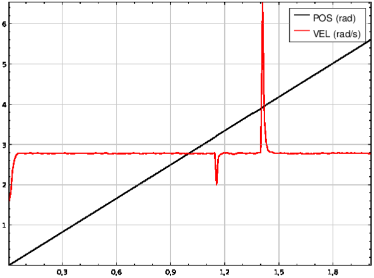




Velocity

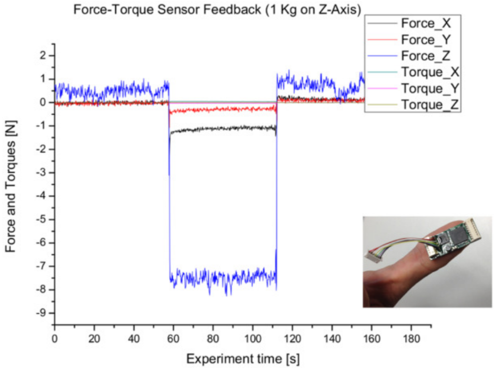
Problems with the velocity

- Derive the position
- For low speeds: Resolution problems $\rightarrow$ Small changes on position
- For high speeds: Computational problems $\rightarrow$ Noise in the derivative

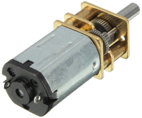


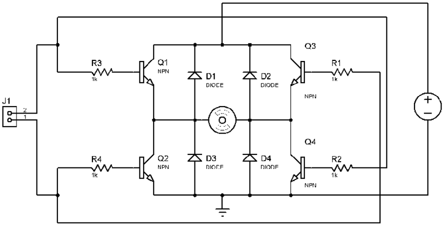
Force

- Resistive
- Piezoelectric
- Capacitive
- Analog
- Digital
- Compression
- Traction
- Flexion
- ....

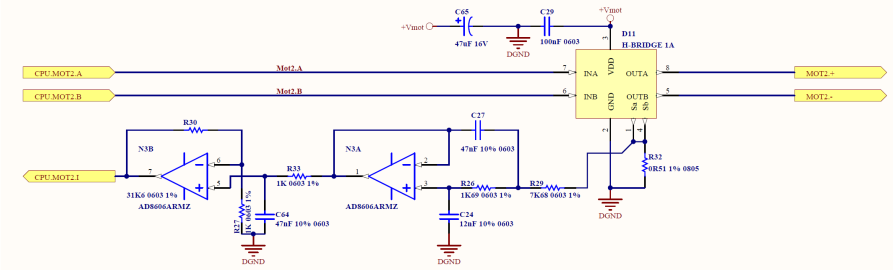


Current





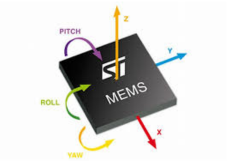
J1
R3
1k
Q1
NPN
D1
DIODE
D2
DIODE
Q3
R1
1k
NPN
R4
1k
Q2
NPN
D3
DIODE
D4
DIODE
Q4
R2
1k
NPN

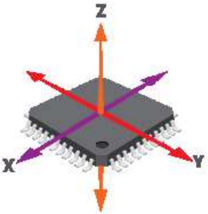


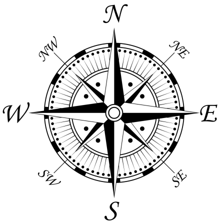
C65
47uF 16V
+Vmot
DGND
C29
100nF 0603
+Vmot
D11
H-BRIDGE 1A
CPU.MOT2.A
Mot2.A
INA
VDD
OUTA
MOT2.+
CPU.MOT2.B
Mot2.B
INB
GND
OUTB
Sa
Sb
MOT2.-
R30
31K6 0603 1%
N3B
AD8606ARMZ
CPU.MOT2.I
R33
1K 0603 1%
R27
1K 0603 1%
C64
47nF 10% 0603
DGND
N3A
AD8606ARMZ
C27
47nF 10% 0603
R26
1K69 0603 1%
C24
12nF 10% 0603
DGND
R29
7K68 0603 1%
R32
0R51 1% 0805
DGND

Inertial

- Accelerometer
- Gyroscope
- Compass





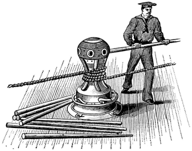


Actuators

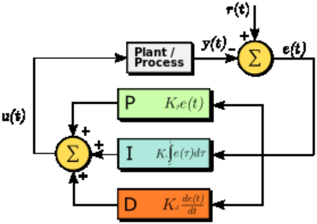
- Hydraulic
- Pneumatic
- Electric
  - DC motors
  - Brushless motors
  - Step motors

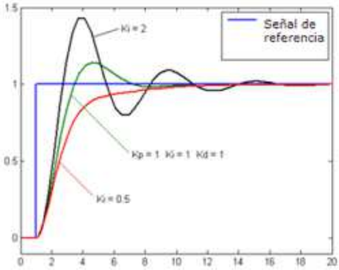
Transmission

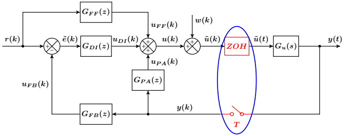
- Gears
- Pulleys
- Capstan
- Direct

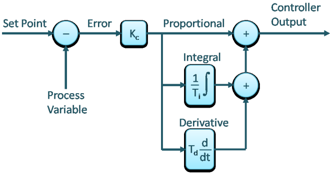


Controllers





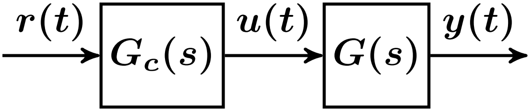




$$G_{\dot{\Theta}_m}(s) = \frac{k_m}{(J_m s + B_m)(L_m s + R_m) + k_b k_m}$$

$$u(t) = K_p \left(e(t) + \tau_D \dot{e}(t) + \frac{1}{\tau_I} \int_0^t e(\tau) d\tau \right)$$

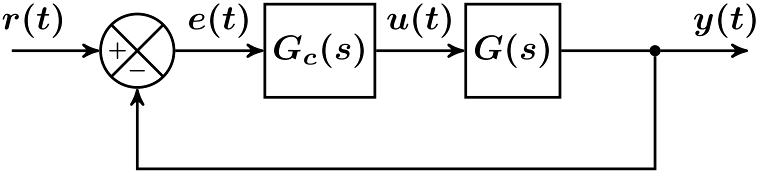
Control systems



- The **output** is the variable to measure and control (y)
- The **input** is the variable that is changed to modify the output (r).
- The **error** is the difference between the input and the output ($e = y - r$)

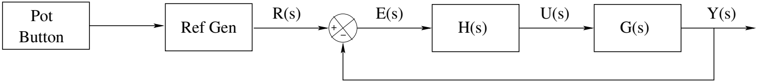
- **Objective**: Make the error be or tend to zero. ($\lim_{t\to\infty} e = 0$)

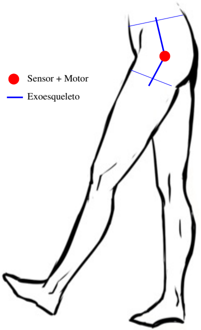
Closed loop control system



- **Feedback**: error signal (*e*)
- The sensibility to perturbations is reduced.
- The sensibility to internal parameters variations is reduced.
- Stability problems.

Walking assistance





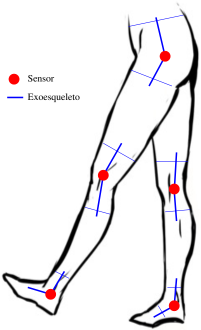
$$G(s) = \frac{A}{s(s+p)}$$

$$H(s) = K_p\left(1 + \tau_d s + \frac{1}{\tau_i s}\right)$$

Walking assistance

Honda Stride Management Assist.

Walking assistance



- Inertia matrix (M)
- Coriolis matrix (C)
- Gravitational torque vector (P)
- Motor torque vector (T)
- Exoskeleton torque vector (d)

$$M(\theta)\ddot{\theta} + C(\theta, \dot{\theta})\dot{\theta} + P(\theta) = T + d$$
$$T = \hat{P} + (1 - \alpha^1)[\hat{M}(\theta)\ddot{\theta} + \hat{C}(\theta, \dot{\theta})\dot{\theta}]$$

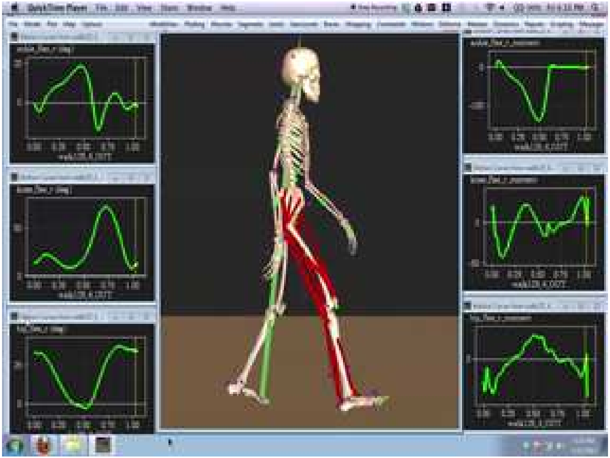
$$M(\theta)\ddot{\theta} + C(\theta, \dot{\theta})\dot{\theta} + P(\theta) = P(\hat{\theta}) + (1 - \alpha^1)[\hat{M}(\theta)\ddot{\theta} + \hat{C}(\theta, \dot{\theta})\dot{\theta}] + d$$

Kazerooni et al., On the Control of the Berkeley Lower Extremity Exoskeleton (BLEEX), ICRA 2005.

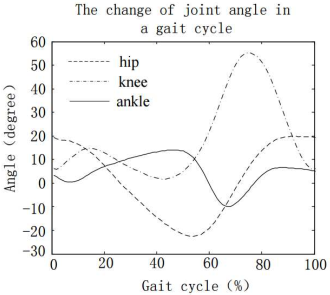
Walking assistance

Cyberdine Robot Suit HAL.

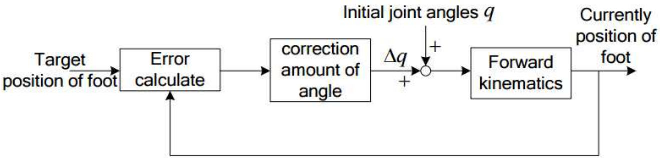
Walking kinematics and dynamics



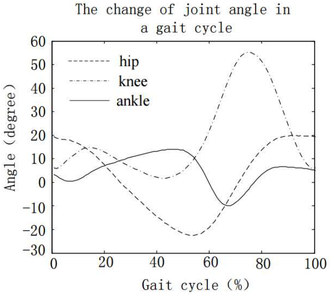
Estimators



- Center of mass
- Kinematic stability
- Dynamic stability
- Velocity stability
- Turn, rotations, accelerations,...



Estimators



- Center of mass
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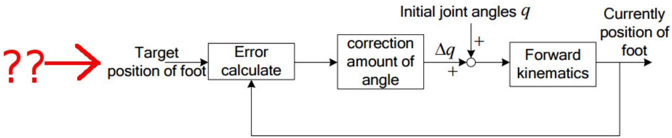
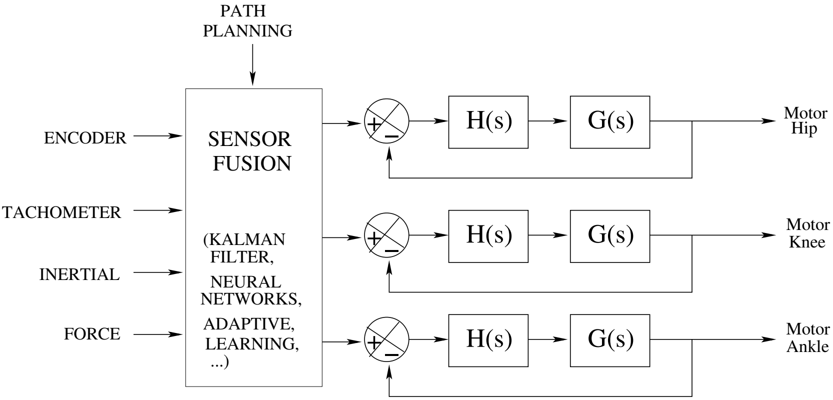


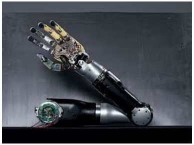
Controller

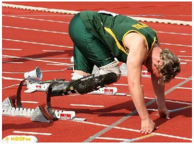

PATH
PLANNING
ENCODER
TACHOMETER
INERTIAL
FORCE
SENSOR
FUSION
(KALMAN
FILTER,
NEURAL
NETWORKS,
ADAPTIVE,
LEARNING,
...)
+
−
H(s)
G(s)
Motor
Hip
Motor
Knee
Motor
Ankle

Exoskeletons

Poses

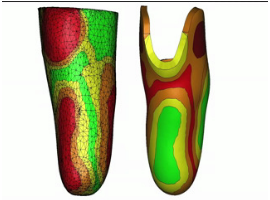
Prostheses

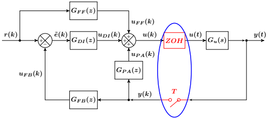


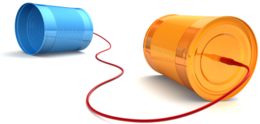


Let's look inside!!!

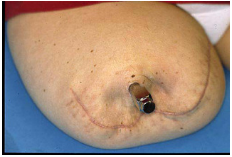
- **Mechanics**
  - Modelling
  - Attachment
  - Plasticity
- **Dynamics**
  - Movement
  - Control
- **Communication**
  - Actuation
  - Sensorization

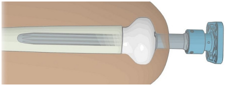


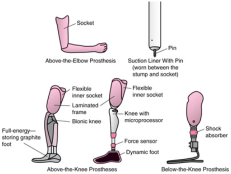


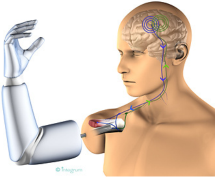


Attachment

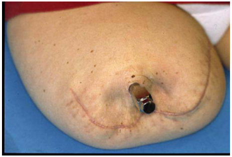


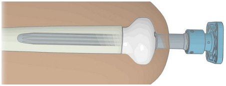


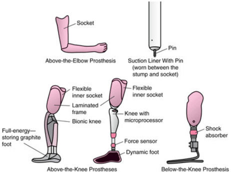

Socket
Above-the-Elbow Prosthesis
Pin
Suction Liner With Pin
(worn between the
stump and socket)
Flexible
inner socket
Laminated
frame
Bionic knee
Full-energy-
storing graphite
foot
Flexible
inner socket
Knee with
microprocessor
Force sensor
Dynamic foot
Shock
absorber
Above-the-Knee Prostheses
Below-the-Knee Prosthesis

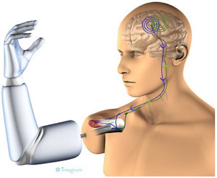


Attachment









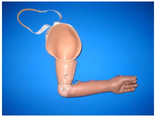
- Pressure ulcers, distention, dermatitis,...

Dynamics

- Passive elements

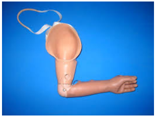
Dynamics

- Passive elements



Dynamics

- Passive elements



- A Prosthesis must be something else!!!!
  - Movement, elasticity
  - Control, feedback
  - Sensorization, communication

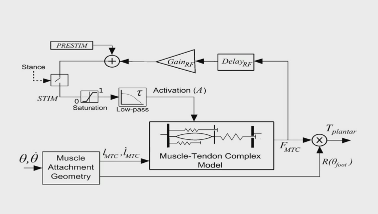
Dynamics


Bionic Propulsion
Stiffness Modulation
Net-Positive Power Assist

Dynamics

Communication

- **Actuation**: Muscle (Nerve) $\rightarrow$ Prosthesis



Upper limb prosthesis

- Many legs $\rightarrow$ Where are the arms?

Upper limb prosthesis

- Many legs $\rightarrow$ Where are the arms?
- Limitations:
  - Degrees of freedom: > 19 ?
  - Excessive weight: (5 Kg) $\rightarrow$ < 1/16 body weight?
  - Autonomy: several days?
  - High cost maintenance: light and resistant materials
  - High prices: $\approx$ 30 k€
  - Response time: slow
  - Feedback: tactile and temperature sensations?

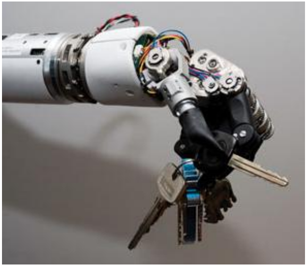
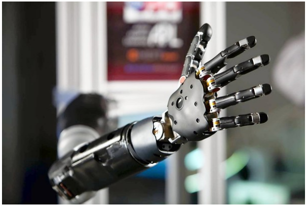
Upper limb prosthesis

- Price reduction with 3D printers




Upper limb prosthesis

- And the others?

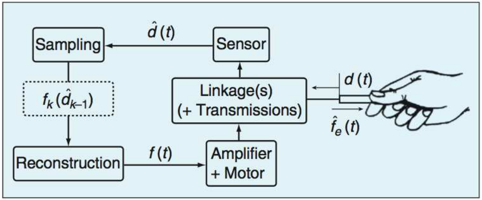





Force feedback

- An infinitely rigid “stick” used as a tool to work remotely.
- Because the “stick” is massless, the operator will feel the object to push.

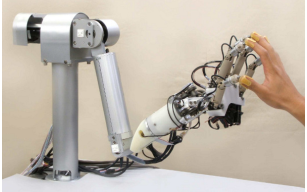
Force feedback

- *First stage*: user action.
- *Second stage*: sampling.
- *Third stage*: transformations on the sampled signal.
- *Fourth stage*: to act on the motor to obtain feedback and real sensations.



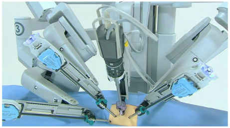
Examples

Examples



Examples

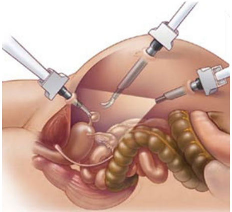


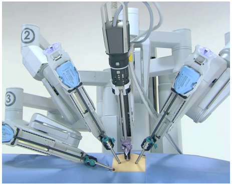



Writing assistance

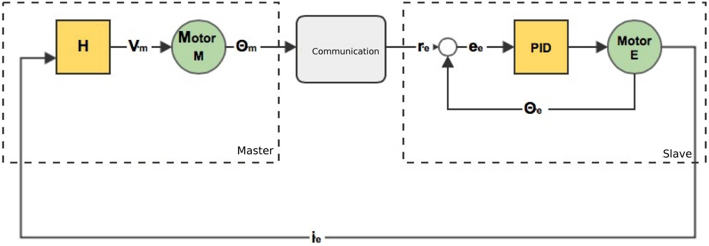
Important milestones

- Anesthesia
- Laparoscopy
- Robotic surgery





Robotic surgery



- $\nexists$ virtual model
- Force sensors
- Position sensors
- Speed sensors
- Contact sensors
- Cameras
- ....

Telesurgery

There is no time for everything!

Course organization

- The course is structured in **2 blocks**:
  - Kinematics and trajectories
  - Haptic devices
- Every block will be independently evaluated, although both blocks are **mandatories** and must be obtained (> 5.0 out of 10.0) **independently**.
- Individual and group deliverables. Group organization depends on number of students and laboratory resources.
- Both blocks have practice parts in the laboratory. The organization of the laboratory will be discussed in the classroom.

Calendar

Day	Topic
10/09/2024	Introduction. DOFs, forward and inverse kinematics
17/09/2024	Trajectory planning. Laboratory*
24/09/2024	**Deliverable D1 (08:59)**
24/09/2024	Laboratory*
01/10/2024	Laboratory*
08/10/2024	**Deliverable D2 (08:59)**
08/10/2024	Haptic systems. Laboratory*
15/10/2024	Laboratory*
31/10/2024	Laboratory*
31/10/2024	**Deliverable D3 (12:59)**

(*) Laboratory meetings will be scheduled outside the pre-assigned hours due to equipment restrictions.
(**) To be confirmed.

Evaluation

- **Deliverable D1** (20 %, individual)
  - To formulate the forward kinematics problem of the laboratory robot.
  - To solve the inverse kinematics problem of the laboratory robot.
- **Deliverable D2** (40 %, group)
  - To formulate the trajectory planning of the laboratory robot.
  - To implement some trajectories in the laboratory robot.
- **Deliverable D3** (40 %, group)
  - To design and implement a gravitational compensator controller
  - To design and implement a virtual spring haptic system

Remember

- 1 ECTS $\rightarrow$ 30h.
- ROB=3 ECTS $\rightarrow$ 90h.
- Presential hours: 28h.
- Extra work: 90h. - 28h. = 62h.

- 7 weeks $\rightarrow$ 12.85h./week
- Presential hours: 4h/week
- **Extra work: 8.85h/week**

THANKS FOR LISTENING!!

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