# NEURARM:
# a Dynamic Robotic Model of the Human Arm

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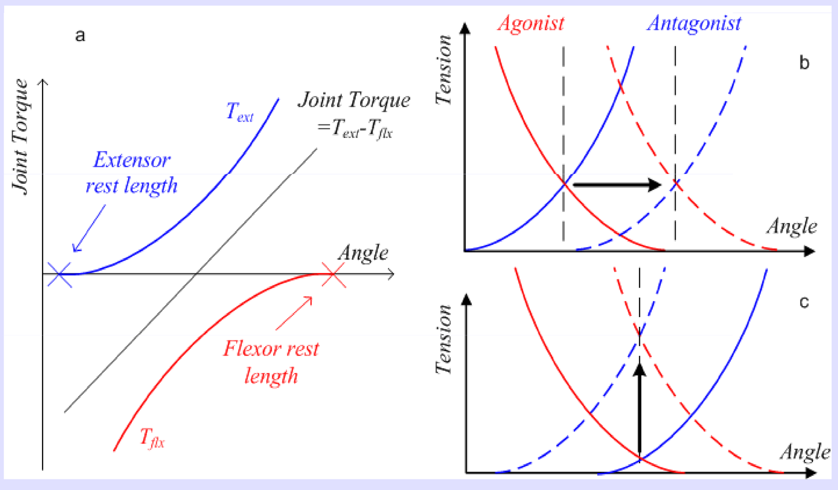
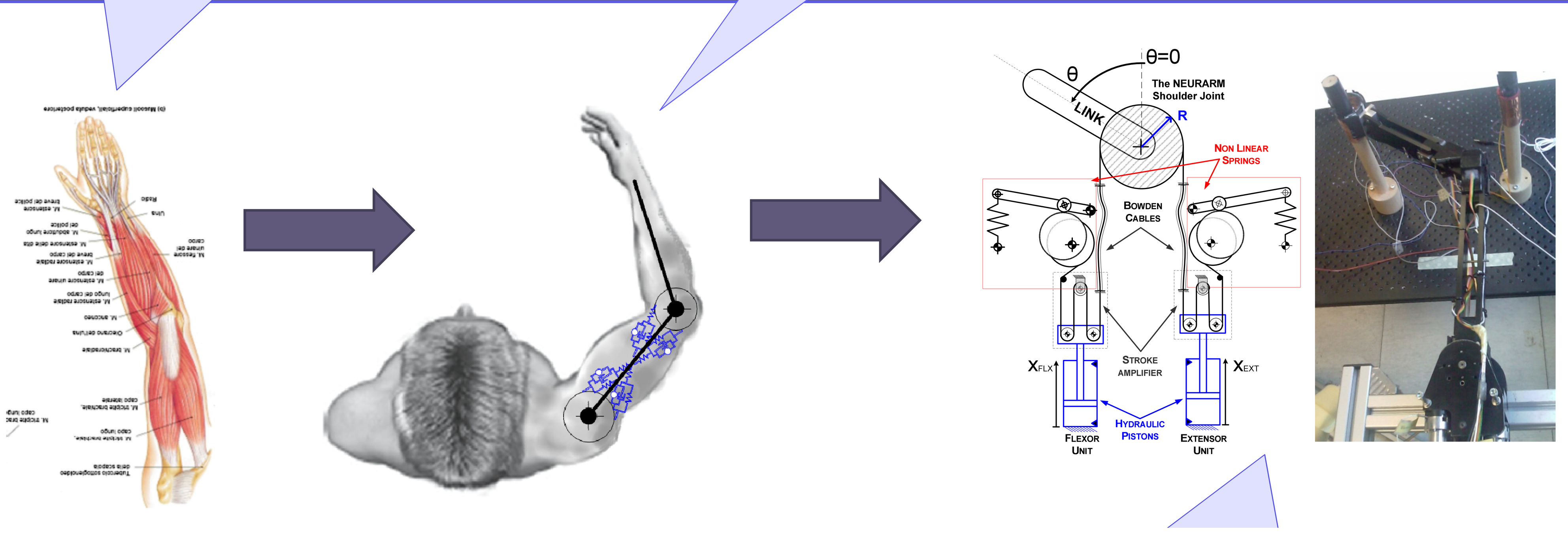
## The biological model

A pair of muscles powering the human joint in an antagonistic configuration exemplifies the main difference between standard industrial robots and biological motor systems. Since muscles have a natural stiffness that varies with the muscle activation level, the central nervous system (CNS) can generate stable equilibrium postures, towards which the arm is attracted, by properly regulating the activation levels of antagonistic muscles (Hogan 1984) The elastic properties of muscles contribute to the finite stiffness/compliance properties of the limb, to the stability of the neuro-musculo-skeletal system in the face of significant feedback delays and even allow for the generation of target movements in absence of sensory feedback, by shifting the equilibrium point (Polit and Bizzi 1979). Moreover, the ability to modulate the stiffness of the limb is fundamental to the control of stable interactions with the environment (Colgate and Hogan 1988) leading to the theory of 'impedance control' (Hogan 1985).

## The cybernetic model

Considering a single joint, the basic idea is that, working against each other, the two opposing spring-like muscles can establish a joint equilibrium position (EP). When the joint is at the EP, the net force and torque acting on it is zero. If moved to the equilibrium position and released, the joint will stay there. If displaced away from the EP by an external force and then released, the spring-like muscle properties will pull the limb back towards the EP. The EP is therefore a stable attractor.




## The NEURARM design approach

## The robotic artifact

| HUMAN ARM | NEURARM |
|---|---|
| Muscles (non-linear actuators) | Hydraulic pistons working with non-linear springs connected on the cable |
| Agonist-antagonist tendon driven | Agonist-antagonist driving cables |
| Tendons fixed on the bones | Two configurations:<br>• cables fixed on the joint (shoulder)<br>• cables fixed on the link (forearm) |
| Tunable contraction force | Electro valves and pressure sensors |
| Muscle spindles (stretching sensors) | Linear potentiometers on the pistons |
| Joint receptors (angle sensors) | Angle sensors on the joints |
| Golgi tendon organs (tension sensors on the tendons) | Load cells on the cables |

The NEURARM joint actuation system replicates the human musculoskeletal system configuration by means of two antagonist compliant actuators (Vitiello et al. 2010, Cattin et al. 2008) . Each antagonist unit consists of three functional elements:

- A non-linear elastic element emulating the muscle's passive elastic behavior. Its force vs. elongation characteristic can be approximated by a quadratic polynomial curve.
- A linear hydraulic actuator combined with a stroke amplifier to mimic the contractile capability of the muscle. These two elements allow the regulation of the rest length of the non linear elastic element. The hydraulic piston is the active component of the transmission system, while the stroke amplifier is used to transform a piston displacement in an larger cable displacement.
- A steel cable transmitting the force to the NEURARM joint by means of a Bowden cable.

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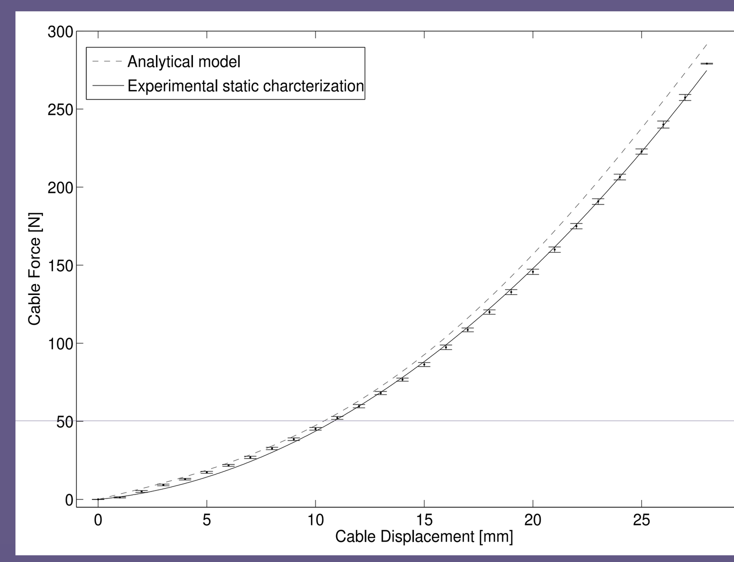
## EXPERIMENTAL RESULTS

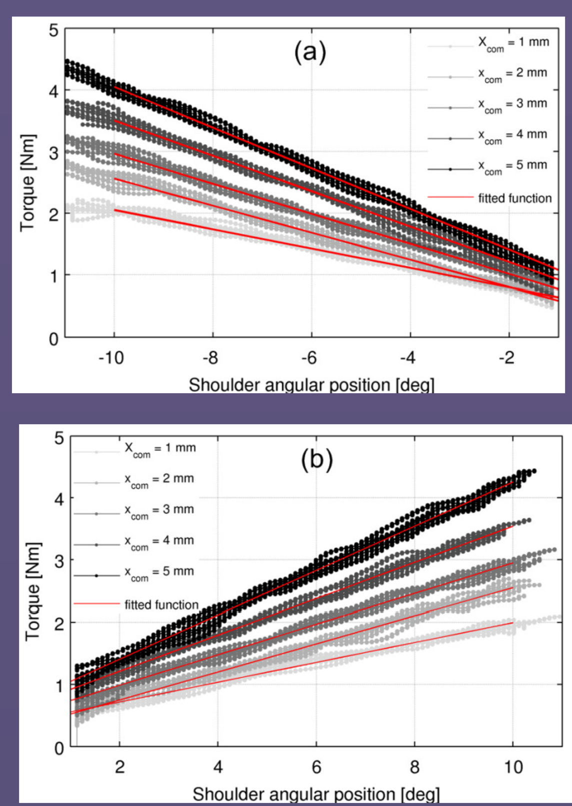
### ...from cybernetic model simulation to robotic artifact test...

Each antagonist actuation unit is provided with a non linear elastic element

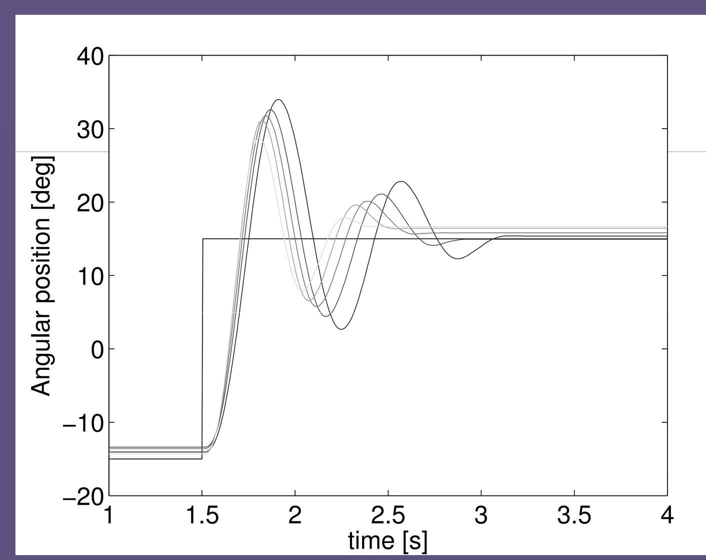



### ...from non linear muscles behavior to variable joint stiffness...

Torque vs displacement at the joint level

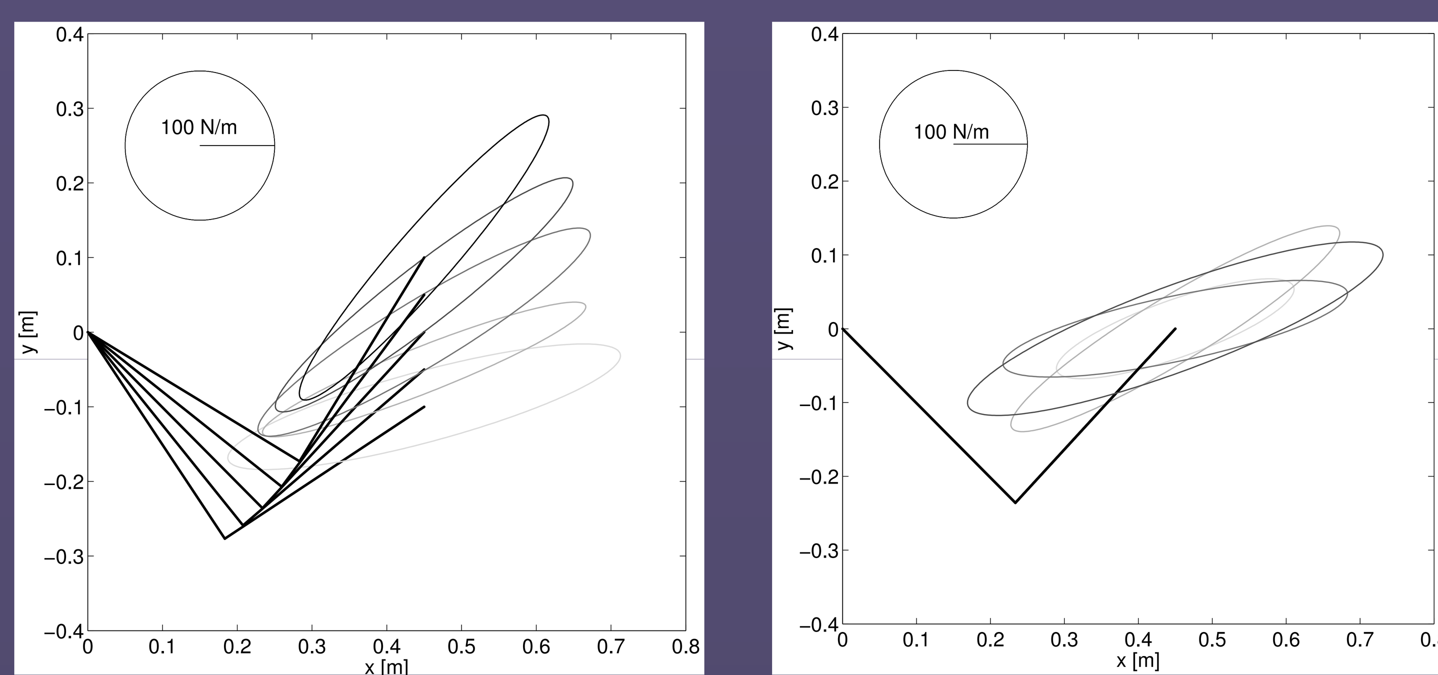



The dynamic effect of antagonist units co-activation at the joint level




### ...from variable joints stiffness to global endpoint characteristics...

End point elastic behavior as a function of joints equilibrium positions and joints stiffness




Fast point to point reaching movement performed by the NEURARM in open-loop fashion