MODELLING LEGGED ROBOT MULTY-BODY DYNAMICS USING HIERARCHICAL VIRTUAL PROTOTYPE DESIGN

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1 BACKGROUND

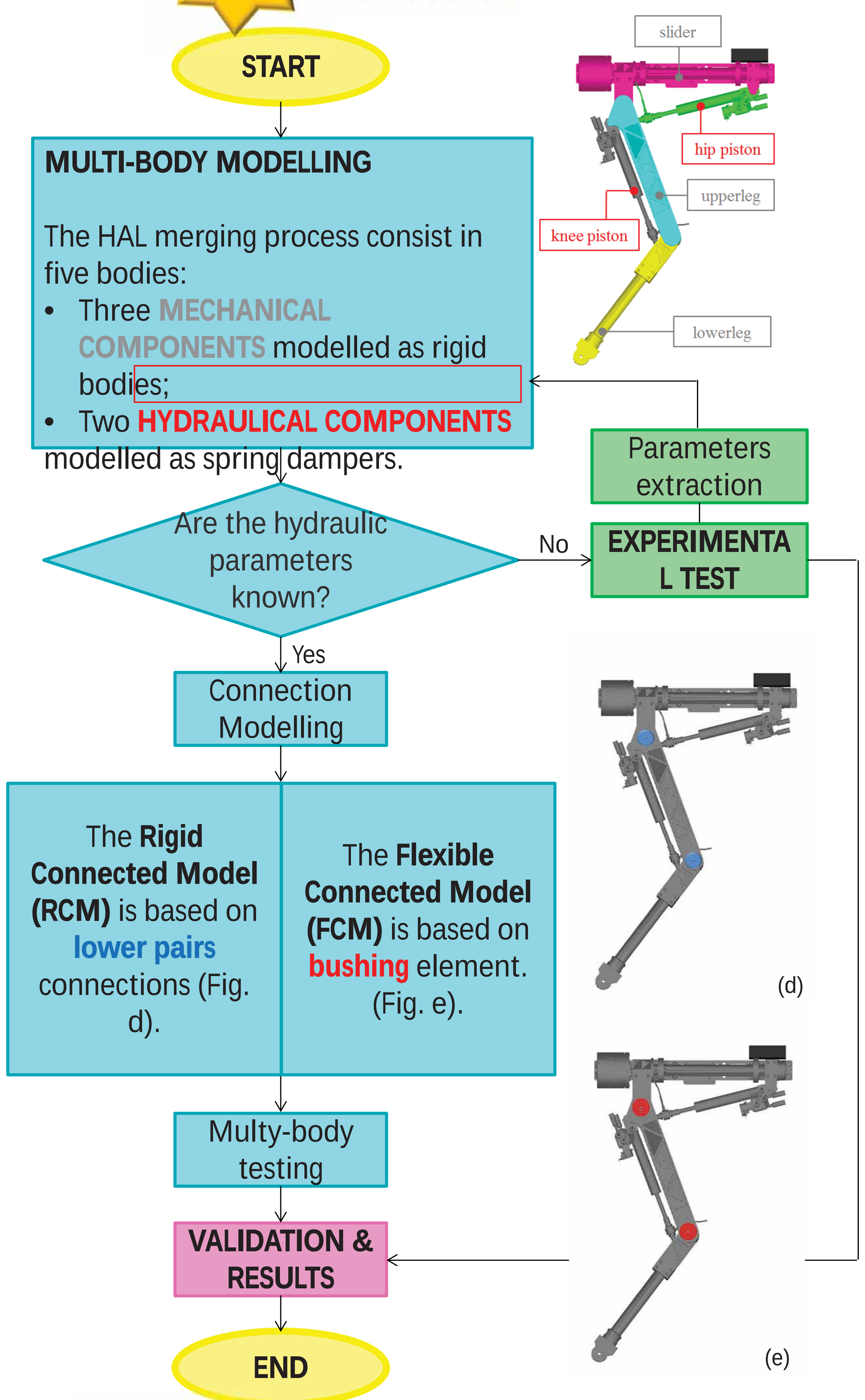
State of Art

- **BIOMIMETICS** is the scientific field which inspires researches in developing **HIGH EFFICIENT ROBOTS**.
- **LEGGED ROBOTS** represents the **BIOMIMETIC ORIENTED** family which performs **COMPLEX TASKS** as running, jumping, gallopping and trotting.
- **MODELLING** these **DYNAMIC FEATURES** is a challenge.

Motivations

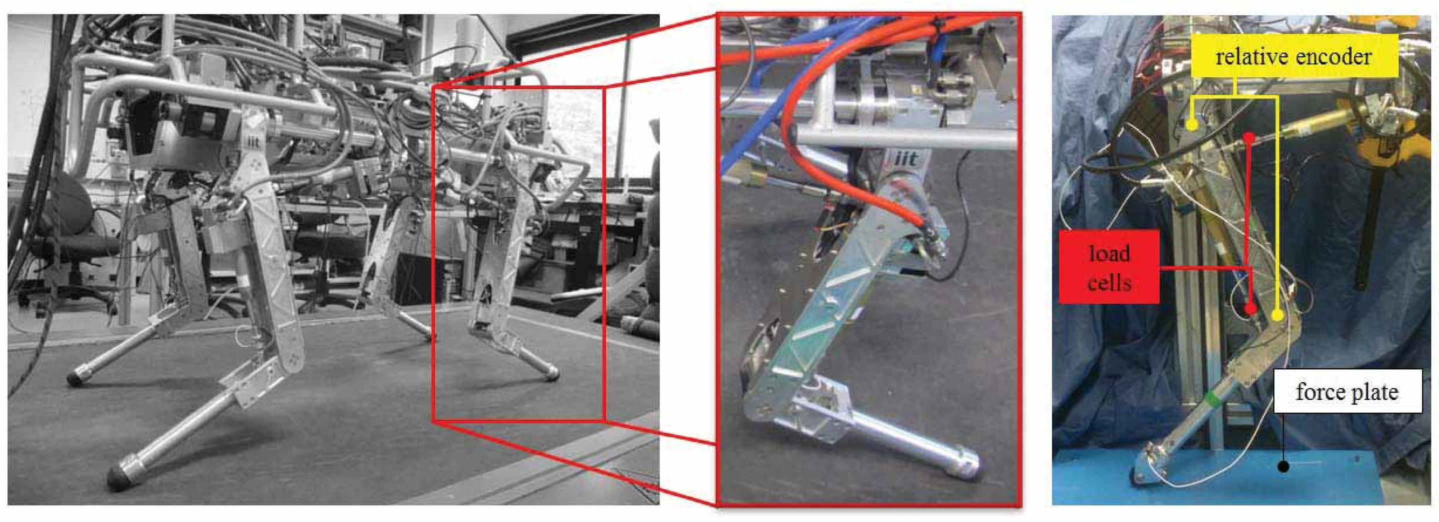
- The traditional solution is **CONTROL THEORY** based on.
- Our solution is **NUMERICAL APPROACH** based on and represents a tradeoff between mechanics and control.
- **VIRTUAL PROTOTYPE DESIGN**, widely used in industrial robotics, is here applied to a **QUADRUPEDAL LEG**.

2 METHOD



3 EXPERIMENTAL TEST

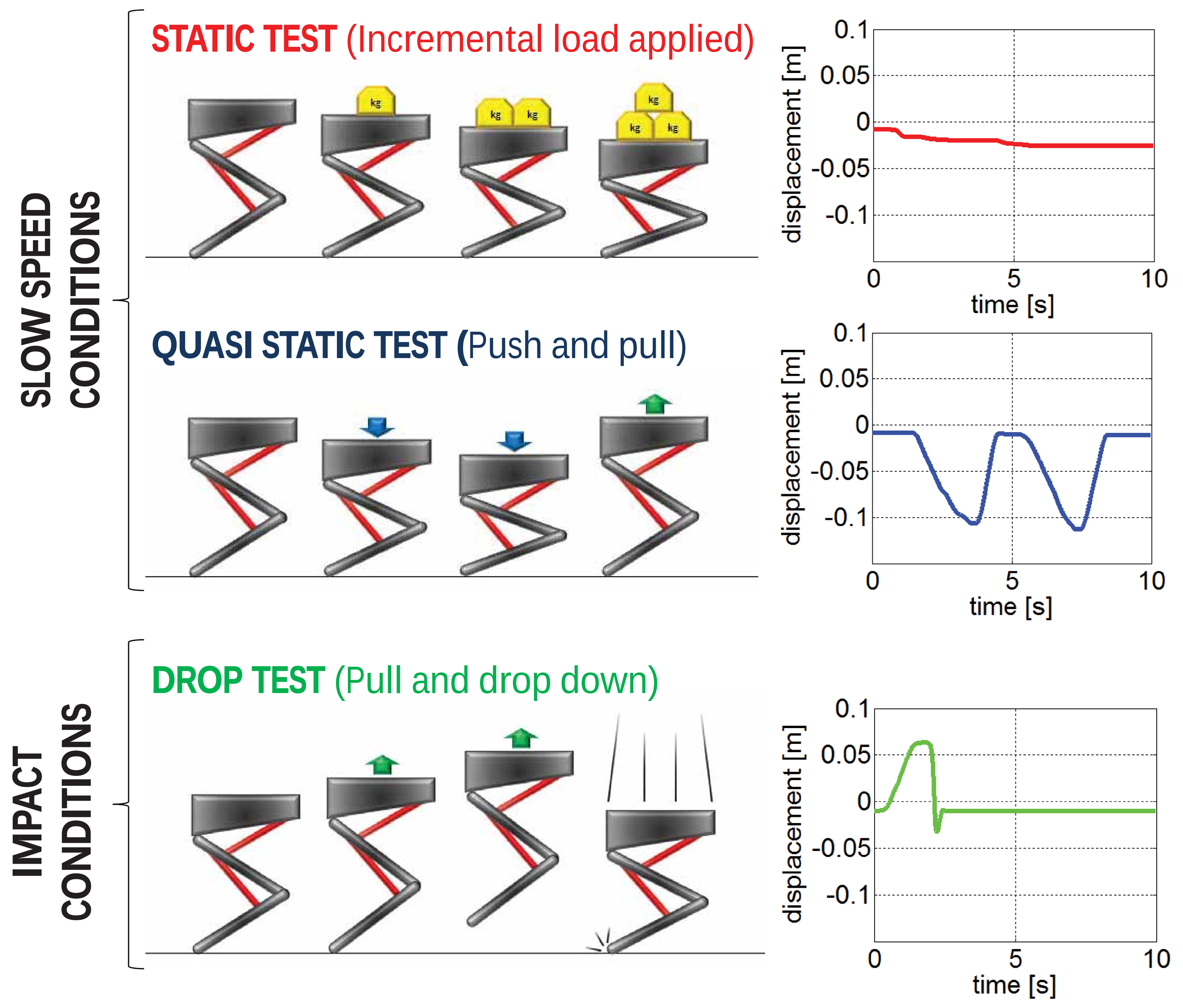
The physical model used in this research is one leg of the **Hydraulic Quadruped (HYQ)** (Fig. a) [1] [2]. This robotic platform is designed to perform **HIGH DYNAMIC TASK LIKE JUMPING, RUNNING, CLIMBING**, etc. It is able to perform both indoor than outdoor operations.



(a) (b) (c)

The **HYDRAULICALLY ACTUATED LEG (HAL)** (Fig. b) has 2 degrees of freedom (DOF) in the sagittal plane, the hip and knee flexion/extension permit the leg to move forward. The leg is built of a light-weight aerospace-grade aluminum alloy and stainless steel with two cylindrical hydraulic actuators. It allows to split the structure in two main groups of components, the **HYDRAULICAL** and the **MECHANICAL** one.

The experimental test, carried out on the instrumented leg (Fig c), have the aim to reproduce several different gaits. They can be classified in **SLOW SPEED** and **IMPACT CONDITIONS**.



Leg vertical displacement

Parameters extraction

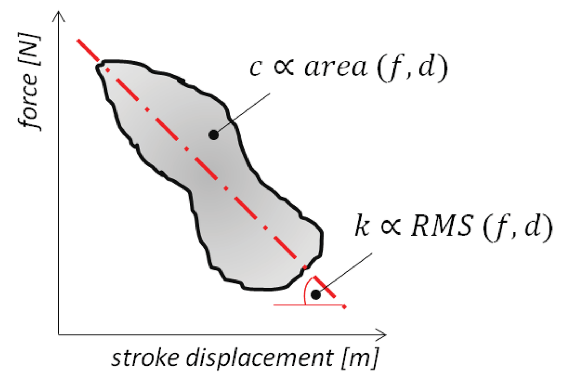
- The hydraulic actuators are modeled as spring-damper element.
- Their modelling process requires the stiffness (**k**) and (**c**) coefficient identification.
- These coefficients are estimated by the **FORCE-STROKE DISPLACEMENT DIAGRAM** for each actuator in both slow speed and impact conditions.

Slow speed condition

- **k** is estimated from the slope of the Root Mean Square (RMS) of the force-stroke diagram.
- **c** is proportional to the area of the force-stroke displacement hysteresis [3].

$$F = \mathbf{k}d$$

$$\Delta E_{cyc} = \int_{cyc} F(t)dx = \mathbf{c}\pi\omega X^2$$

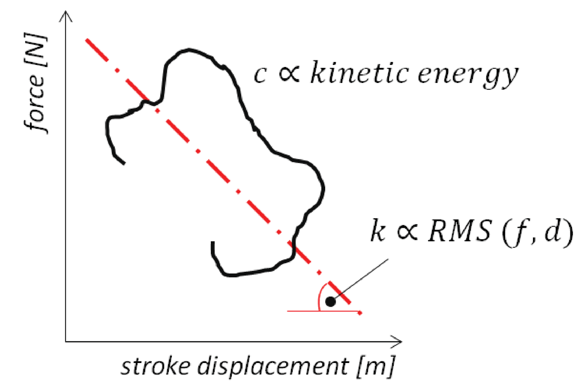


Impact condition

- **k** is estimated from the slope of the Root Mean Square (RMS) of the force-stroke diagram.
- **c** is proportional to the body kinetic energy during the drop [4].

$$F = \mathbf{k}d$$

$$m{v_i}^2 = \mathbf{c}\frac{2\pi^2}{\Delta T}{\Delta l_{max}}^2$$



Experimental test output quantities

- **LOAD CELL FORCES**
- **JOINTS ROTATIONS**
- **GROUND REACTION FORCES.**

4 MULTI-BODY MODELLING

Multi-body testing

- The **DYNAMICS** solution is **NUMERICAL METHOD** based on.
- Gear's **DIFSUB** integrator is chosen. It is a multi-step integrator based on Backward-Difference Formulae.
- The **HAL MBM** is tested in **INVERSE DYNAMIC** and **FORWARD DYNAMIC** conditions.
- The **HAL MBM** reproduces the same test of the experimental one, namely the **STATIC**, the **QUASI STATIC** and the **DROP TEST**.
- Both the **RCM** and the **FCM** are tested in these conditions to verify the influence of **FLEXIBLE CONNECTION** on the **GROUND REACTION FORCE PROPAGATION**.

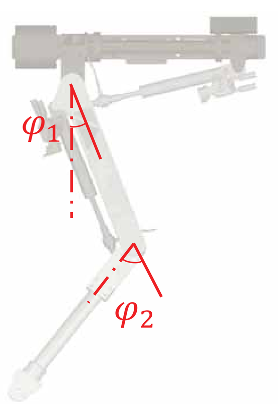
Inverse Dynamics

- The inverse dynamic condition aimed to **VALIDATE** the parameters estimated for the cylindrical actuators.

$$\tau = f(MBM, q)$$

INPUT → model and joints rotations (φ_1, φ_2)

OUTPUT→ forces compared with the load cell data



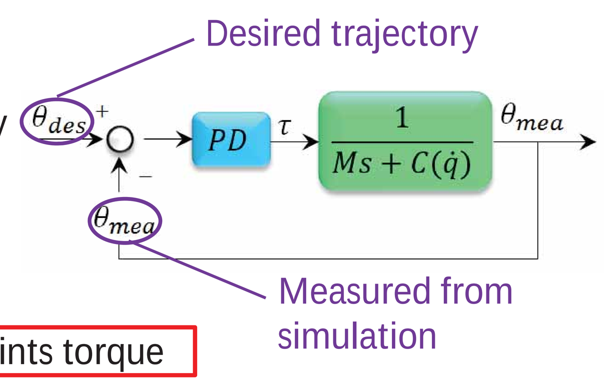
Forward Dynamics

- The forward dynamic condition aimed to apply a **PD control** law to the validated model.

$$q = f(MBM, \tau)$$

INPUT → model and joints torque

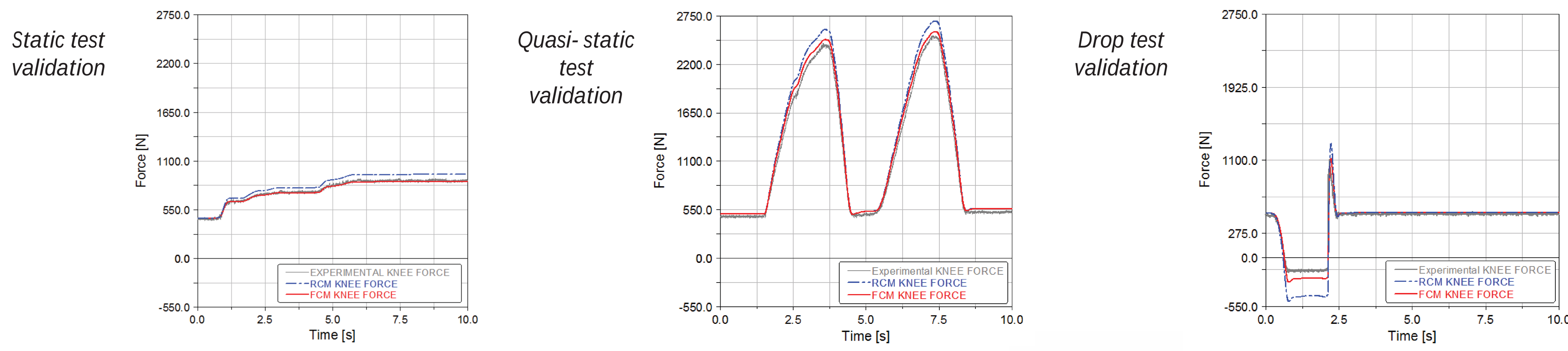
OUTPUT→ joints rotations to be used in the control law



5 VALIDATION & RESULTS

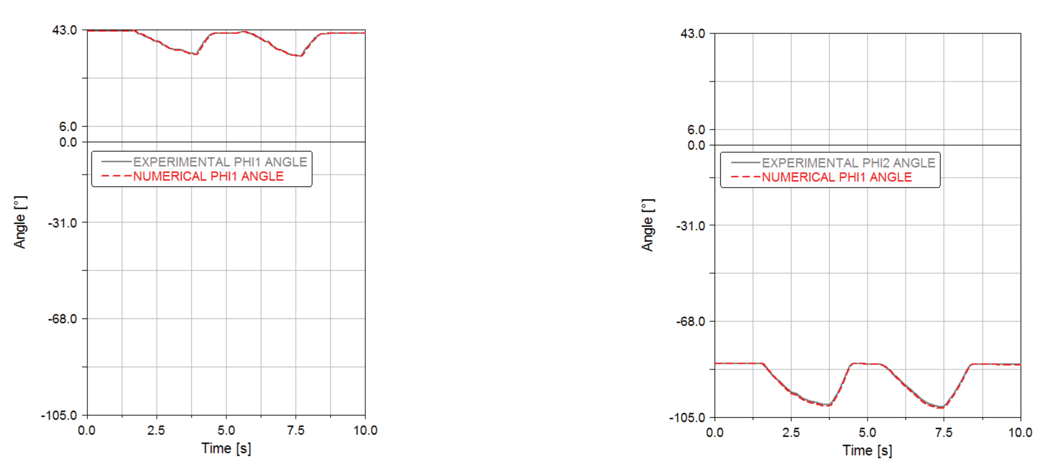
Inverse dynamic condition results

- The **HAL MBM VALIDATION** is reached thanks to the **AGREEMENT** between numerical and experimental results.
- The **FCM** model gives, as expected, **BETTER RESULTS** than the **RCM** one.



Forward dynamic condition results

- Once the HAL MBM is validated, a **PD POSITION CONTROL LAW** is established.
- The HAL MBM is subjected to a vertical sinusoidal displacement.
- The agreement between numerical and experimental angles shows a good implementation of the control law.



6 CONCLUSION

- A simplified MBM model of a quadruped leg is presented.
- We demonstreated the MBM efficiency owed to the agreement between numerical and experimental results.
- The model is useful from the Control Engineers to test control performances considering the distributed inertia.

Future investigation

- Distributed flexibility.
- Force control law.
- Whole HyQ MBM model.

ACKNOWLEDGEMENT

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