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Design and Control of an Industrial Wooden Robot

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RobEcolo

RobEcolo => Reduce the environmental impact of industrial robots

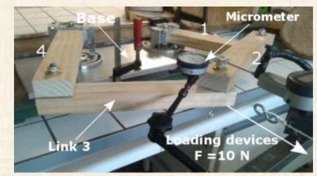
Methodology

Acetylated Wood (Accoya Pine, Beech)

- Good ratio stiffness-to-mass
- Durability
- Dimensional stability

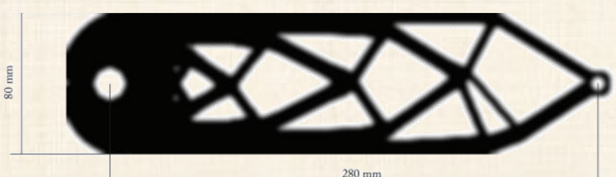
Elastic Models

- Modeling of wood for robotics
- Deformations and vibrations of the wooden robot



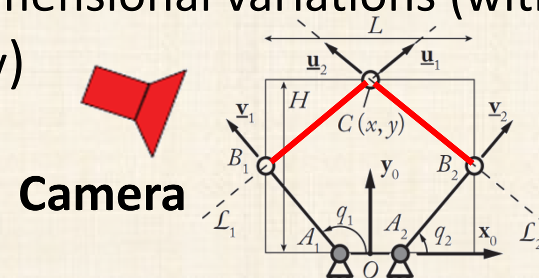
Robust Design

- To deal with the wood mechanical properties uncertainty



Sensor-based Control

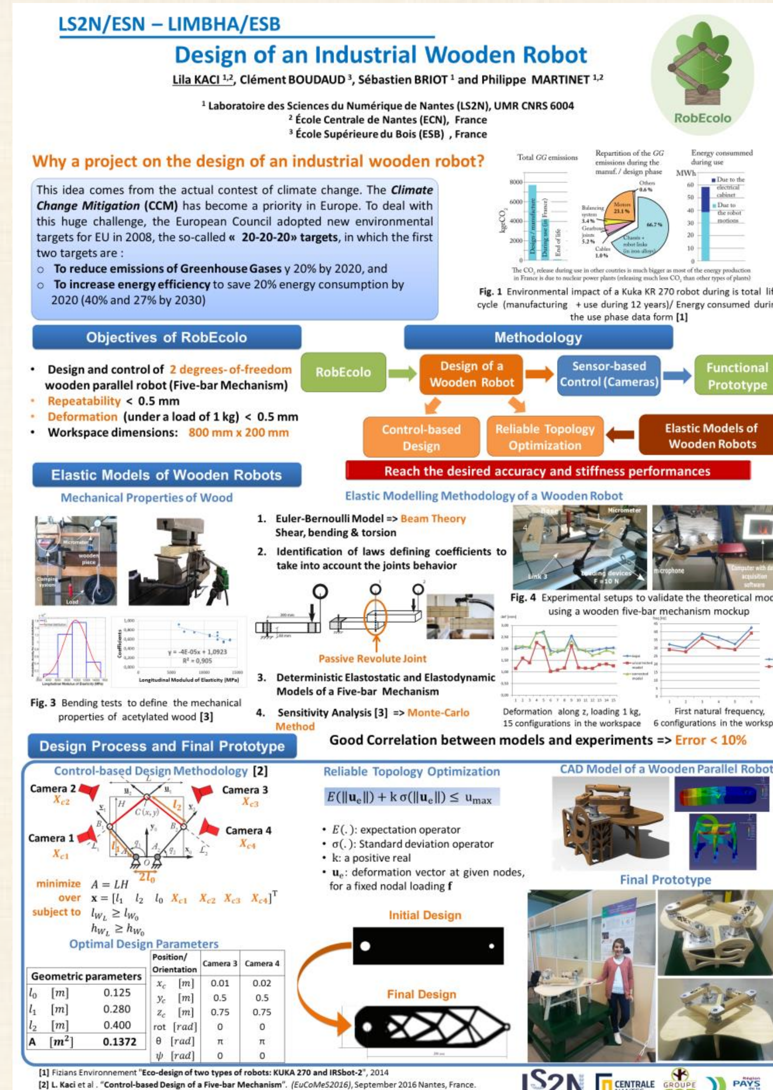
- To deal with the errors due to the wood dimensional variations (with humidity)



Reach the desired accuracy and stiffness of the robot

RobEcolo

C10



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Design of an Industrial Wooden Robot

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Why a project on the design of an industrial wooden robot?

This idea comes from the actual contest of climate change. The ***Climate Change Mitigation*** **(CCM)** has become a priority in Europe. To deal with this huge challenge, the European Council adopted new environmental targets for EU in 2008, the so-called **« 20-20-20» targets**, in which the first two targets are :

- **To reduce emissions of Greenhouse Gases** y 20% by 2020, and
- **To increase energy efficiency** to save 20% energy consumption by 2020 (40% and 27% by 2030)

Fig. 1 Environmental impact of a Kuka KR 270 robot during is total life cycle (manufacturing + use during 12 years)/ Energy consumed during the use phase data form **[1]**

Objectives of RobEcolo

- **Design and control of** 2 degrees-of-freedom **wooden parallel robot (Five-bar Mechanism)**
- Repeatability **< 0.5 mm**
- Deformation **(under a load of 1 kg) < 0.5 mm**
- **Workspace dimensions:** 800 mm x 200 mm

Methodology

RobEcolo → Design of a Wooden Robot → Sensor-based Control (Cameras) → Functional Prototype

Control-based Design; Reliable Topology Optimization ← Elastic Models of Wooden Robots

Reach the desired accuracy and stiffness performances

Elastic Models of Wooden Robots

Mechanical Properties of Wood

Fig. 3 Bending tests to define the mechanical properties of acetylated wood **[3]**

Elastic Modelling Methodology of a Wooden Robot

1. **Euler-Bernoulli Model =>** Beam Theory
   Shear, bending & torsion
2. **Identification of laws defining coefficients to take into account the joints behavior**

Passive Revolute Joint

3. **Deterministic Elastostatic and Elastodynamic Models of a Five-bar Mechanism**
4. **Sensitivity Analysis [3] =>** Monte-Carlo Method

Fig. 4 Experimental setups to validate the theoretical models using a wooden five-bar mechanism mockup

Deformation along z, loading 1 kg, 15 configurations in the workspace

First natural frequency, 6 configurations in the workspace

Good Correlation between models and experiments => Error < 10%

Design Process and Final Prototype

Control-based Design Methodology [2]

Camera 1 X_{c1}, Camera 2 X_{c2}, Camera 3 X_{c3}, Camera 4 X_{c4}

$$\text{minimize } A = LH \quad \text{over } \mathbf{x} = [l_1 \quad l_2 \quad l_0 \quad X_{c1} \quad X_{c2} \quad X_{c3} \quad X_{c4}]^T \quad \text{subject to } l_{W_L} \geq l_{W_0},\ h_{W_L} \geq h_{W_0}$$

Optimal Design Parameters

Geometric parameters	
l_0 $[m]$	0.125
l_1 $[m]$	0.280
l_2 $[m]$	0.400
A $[m^2]$	**0.1372**

Position/ Orientation	Camera 3	Camera 4
x_c $[m]$	0.01	0.02
y_c $[m]$	0.5	0.5
z_c $[m]$	0.75	0.75
rot $[rad]$	0	0
θ $[rad]$	π	π
ψ $[rad]$	0	0

Reliable Topology Optimization

$$E(\|\mathbf{u}_e\|) + k\,\sigma(\|\mathbf{u}_e\|) \leq u_{max}$$

- $E(.)$: expectation operator
- $\sigma(.)$: Standard deviation operator
- k: a positive real
- $\mathbf{u}_e$: deformation vector at given nodes, for a fixed nodal loading **f**

Initial Design

Final Design

CAD Model of a Wooden Parallel Robot

Final Prototype

[1] Fizians Environnement "**Eco-design of two types of robots: KUKA 270 and IRSbot-2**", 2014
[2] L. Kaci et al . "**Control-based Design of a Five-bar Mechanism**". *(EuCoMeS2016)*, September 2016 Nantes, France.
[3] L. Kaci et al. "**Elastostatic Modelling of a Wooden Parallel Robot.**" *(CK2017)*, May 22-24, 2017 Futuroscope-Poitiers, France.