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# Mixing AI and deterministic methods for the design of a transfer system for frail people

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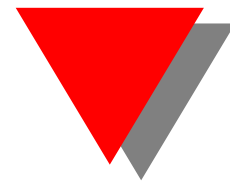


**Mixing AI and deterministic methods for the  
design of a transfer system for frail people**

**Jean-Pierre Merlet**

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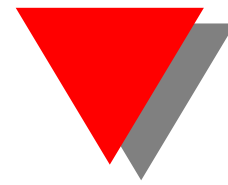
**HEPHAISTOS project team**



# Assistance for frail people

Major issues for assistance at home

- **mobility**: helping autonomous mobility such as walking and transfer (e.g. sit to stand)
- **monitor** the mobility for the medical community



# Assistance for frail people

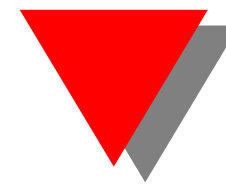
## Major issues

- **mobility**: helping autonomous mobility such as walking and transfer (e.g. sit to stand)
- **monitor** the mobility for the medical community

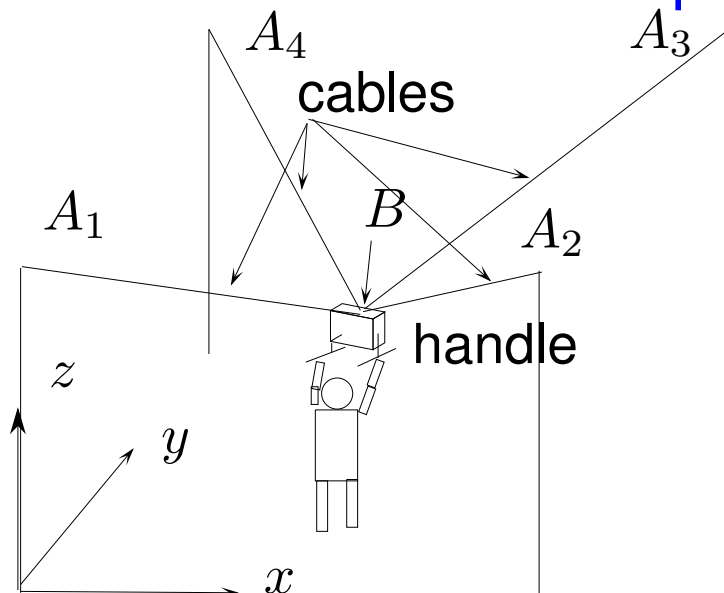
## Assisting mobility

- is a **mechanically demanding task**
- mobility device should be **minimally intrusive**

# A smart transfer system



Based on a **cable-driven parallel robot (CDPR)**



- winches located at the  $A_i$  points allows to change the lengths  $L_0$  of the cables
- control of the  $L_0$  allows to move  $B$  in any direction
- sensors at  $B$  allows to **measure walking characteristics**
- **large lifting force, low cost and intrusivity**

# Safety concerns



We have a **safety critical device** so that the **design** is important

Example of design problem to consider

*What will be the maximal value of the cable tensions when the end-user moves in any place in the room ?*

# Safety concerns



*What will be the maximal value of the cable tensions when the end-user moves in any place in the room ?*

Assume that  $\mathbf{X}$ , the position  $(x, y, z)$  of  $B$  is given. It is possible to establish a square system of equations such that

$$\mathcal{H}(x, y, z, \mathbf{L}_0, \tau) = 0 \quad \tau = \text{cable tensions}$$

Hence we have to solve a **constrained global optimization** problem:

$$\text{Find Max } \tau_i \quad \forall \mathbf{X} \in \mathcal{W} \quad \text{subjected to } \mathcal{H}(x, y, z, \mathbf{L}_0, \tau) = 0$$

# Safety concerns



*What will be the maximal value of the cable tensions when the end-user moves in any place in the room ?*

Hence we have to solve a **global optimization** problem

Find  $\text{Max } \tau_i \quad \forall \mathbf{X} \in \mathcal{W}$  subjected to  $\mathcal{H}(x, y, z, \mathbf{L}_0, \tau) = 0$

that takes into account the **cable model**

$$x_b = F_x \left( \frac{L_0}{EA_0} + \frac{\sinh^{-1}(F_z) - \sinh^{-1}\left(F_z - \frac{\mu g L_0}{F_x}\right)}{\mu g} \right)$$
$$z_b = \frac{F_z}{EA_0} - \mu g L_0^2 / 2 + \frac{\sqrt{F_x^2 + F_z^2} - \sqrt{F_x^2 + (F_z - \mu g L_0)^2}}{\mu g}$$



# Safety concerns



A possibility to estimate the maximal tensions:

- **sample** in  $x, y, z$  the possible poses  $\mathbf{X}$  in  $\mathcal{W}$  (or sample the possible  $\mathbf{L}_0$ )
- for each sample solve  $\mathcal{H}(x, y, z, \mathbf{L}_0, \tau) = 0$  in  $(\mathbf{L}_0, \tau)$  (in  $(\mathbf{X}, \tau)$ )
- retain the largest  $\tau$  over all samples

# Kinematics



for each sample solve  $\mathcal{H}(x, y, z, \mathbf{L}_0, \tau) = 0$

- finding the  $\mathbf{L}_0$  that satisfy  $\mathcal{H} = 0$  for a given position  $\mathbf{X}$  of the robot is called the **inverse kinematics (IK)**
- reciprocally finding the position  $\mathbf{X}$  that satisfy  $\mathcal{H} = 0$  for given  $\mathbf{L}_0$  is called the **direct kinematics (DK)**

Both problems are **extremely challenging**:

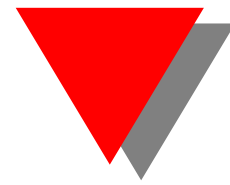
- there are usually several solutions
- currently only **interval analysis** has allowed to find these solutions
- computation time: **several hours**
- there is **no known method** to determine in advance the **number of solutions of  $\mathcal{H} = 0$**

# Using AI



Focus on **inverse kinematics**

- **non classical AI problem**: several outputs for a fixed input but the number of output is not known in advance
- IA has provided us several cases with **3 solutions** lying on different **branches**
- from these examples we can calculate by **continuation** the IK of other positions and attribute the solution to one of the 3 branches
- hence we may constitute a **learning base** for each branch together with a **verification set** that provide the **IK exact solutions**



# Multi-layer perceptron (MLP)

systematic tests with MLP

- with  $\{1,2,3,4,5,6\}$  layers
- with  $10k$  neurons,  $k \in [1, 20]$
- with all combinations of activation functions among a set of 5 classical activation functions
- we compare the result of the MLPs on the verification set



# Multi-layer perceptron: results

Test on a  $6 \times 6$  meters CDPR

None of the tested MLP provides the IK with a reasonable accuracy

For the best MLPs we get:

- largest error on the  $\mathbf{L}_0$ : 1 meters
- mean error: 0.6 meters
- maximal error on the  $\tau$ : 200 %
- **BUT**: some of the MLPs provide good estimates for some components of  $\mathbf{L}_0$  and/or for some of the  $\tau_i$

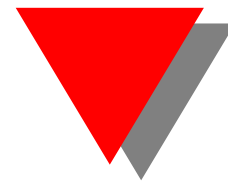
# Strategy



for getting exactly the IK solutions:

- use several MLP that provide several estimates of a solution
- combine these estimates to build new estimates
- use the various estimates as guess for the [Newton method](#)
- if Newton converge we get an IK solution

# Strategy



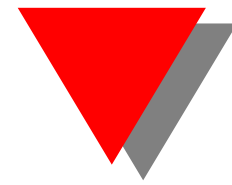
for getting the exact results:

- use several MLP that provide several estimates of a solution
- combine these estimates to build new estimates
- use the various estimates as guess for the [Newton method](#)
- if Newton converge we get an IK solution

**IT WORKS!:**

- with the right strategy we get 100% of exact result for a very large verification set
- the computation time is very low, a few ms (compared to several hours with IA)

# Conclusion



- AI mixed with a deterministic numerical method allows to solve very efficiently the IK problem
- we don't know to solve the DK problem because we are unable to determine cases with the maximum number of solutions



# Conclusion



## Prospective

- we have sampled the workspace at various position  $\{\mathbf{X}_1, \mathbf{X}_2, \dots, \mathbf{X}_n\}$  so we don't have the exact maximum for the  $\tau$ 
  - use IA to compute exactly the maximum in a ball around each  $\mathbf{X}_i$
  - develop an **interval neural network** that takes as input intervals for  $x, y, z$  and outputs intervals for the  $\tau$  ?

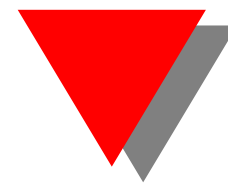
# Conclusion



## Prospective

- cable properties change over time and affect the robot behavior which is redundantly measured: AI use to monitor these changes for **preventive maintenance** ?

# Conclusion



## Prospective

- the transfer device offers large amount of data regarding walking
  - use of AI for exploiting these data (e.g. to detect emerging pathologies) ?
  - AI cannot be exclusive: may fail to detect **rare events** that may be a very early warning of the appearance of a pathology