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

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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

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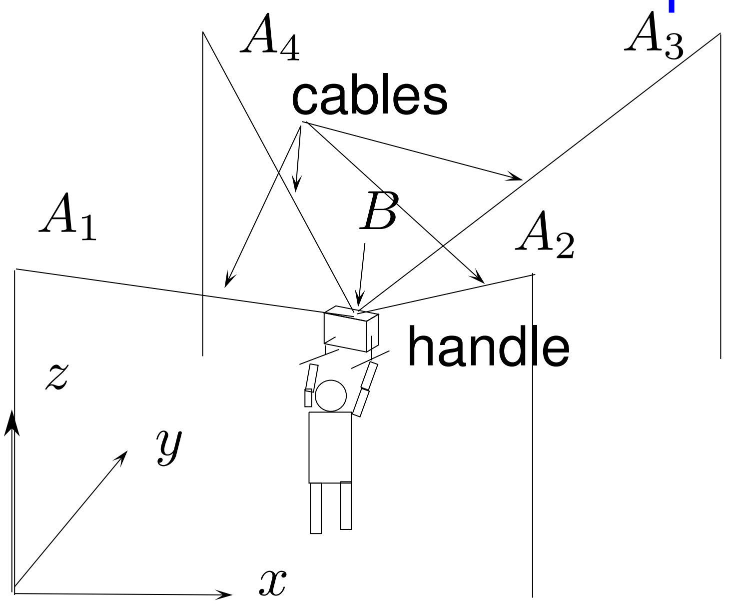
- mobility: helping autonomous mobility such as walking and transfer (e.g. sit to stand)
- monitor the mobility for the medical community

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 $\mathbf{L_0}$ of the cables
- control of the $\mathbf{L_0}$ 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 ?

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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

$$\mathcal{H}(x, y, z, \mathbf{L_0}, \tau) = 0 \qquad \tau = \text{cable tensions}$$

Hence we have to solve a constrained global optimization problem:

$$\text{Find Max } \tau_i \ \ \forall \mathbf{X} \in \mathcal{W} \ \ \text{subjected to } \mathcal{H}(x, y, z, \mathbf{L_0}, \tau) = 0$$

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that takes into account the cable model

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

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

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 τ 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 6×6 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 τ: 200 %
- BUT: some of the MLPs provide good estimates for some components of $\mathbf{L_0}$ and/or for some of the τ_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

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for getting the exact results:

- use several MLP that provide several estimates of a solution
- combine these estimates to build new estimates
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- 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 $\{\mathbf{X}_1, \mathbf{X}_2, \ldots \mathbf{X}_n\}$ so we don't have the exact maximum for the τ
  - 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 τ ?

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