A Scalable and Distributed Solution to the Inertial Motion Capture Problem

Manon Kok[⋆], Sina Khoshfetrat Pakazad[⋆], Thomas B. Schön[†], Anders Hansson[⋆] and Jeroen D. Hol[‡]

[⋆]Linköping University, Sweden
[†]Uppsala University, Sweden
[‡]Xsens Technologies, the Netherlands

LINKÖPING UNIVERSITY

Background:

Manon Kok, Jeroen D. Hol and Thomas B. Schön, An optimization-based approach to human body motion capture using inertial sensors. Proceedings of the 19th World Congress of the International Federation of Automatic Control (IFAC), pp. 79-85, Cape Town, South Africa, August 2014.

Sina Khoshfetrat Pakazad, Anders Hansson, and Martin S. Andersen, Distributed primal-dual interior-point methods for solving loosely coupled problems using message passing, ArXiv e-prints, June 2015, arXiv:1502.06384.

Background:

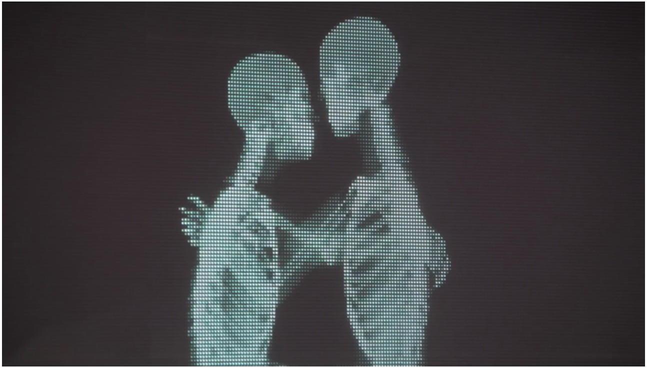
Manon Kok, Jeroen D. Hol and Thomas B. Schön, An optimization-based approach to human body motion capture using inertial sensors. Proceedings of the 19th World Congress of the International Federation of Automatic Control (IFAC), pp. 79-85, Cape Town, South Africa, August 2014.

Sina Khoshfetrat Pakazad, Anders Hansson, and Martin S. Andersen, Distributed primal-dual interior-point methods for solving loosely coupled problems using message passing, ArXiv e-prints, June 2015, arXiv:1502.06384.

Outline:

What is inertial sensor motion capture?
How can the structure in the problem be exploited using message passing?

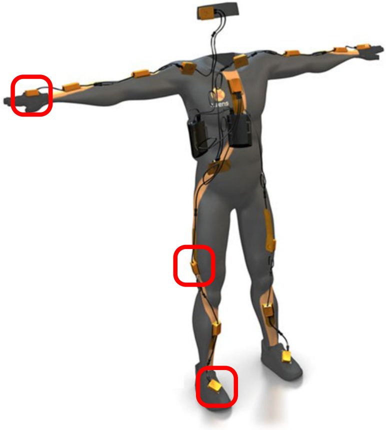
Inertial motion capture



https://www.youtube.com/watch?v=PnDgZuGIhHs

Inertial motion capture

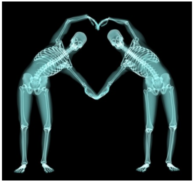
Inertial motion capture

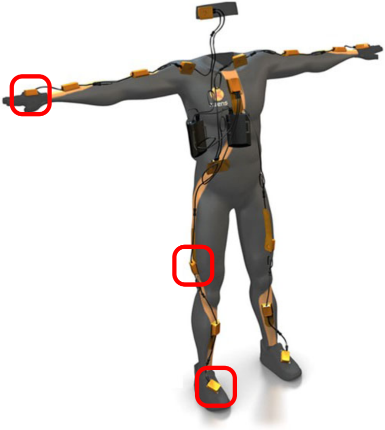


17 sensors placed on the body

Inertial motion capture

Estimate the relative position and orientation of body segments.





17 sensors placed on the body

Model

Inertial sensors:

- Accelerometers
- Gyroscopes

The inertial sensors provide information about the *change* in position and orientation.

Model

The inertial sensors provide information about the *change* in position and orientation.

The position and orientation of the sensors on the body is approximately constant.

Model

The inertial sensors provide information about the *change* in position and orientation.

The position and orientation of the sensors on the body is approximately constant.

The body segments are connected at the joints.

Model

The inertial sensors provide information about the *change* in position and orientation.

The position and orientation of the sensors on the body is approximately constant.

The body segments are connected at the joints.
$\Rightarrow$ constraint

Solving the inertial motion capture problem

$$\begin{aligned} \underset{z}{\text{maximize}} \quad & p(z \mid y) \\ \text{subject to} \quad & c(z) = 0 \end{aligned}$$

Solving the inertial motion capture problem

$$\begin{aligned} \underset{z}{\text{maximize}} \quad & p(z \mid y) \\ \text{subject to} \quad & c(z) = 0 \end{aligned}$$

- Post-process data to obtain smoothing estimate.

Solving the inertial motion capture problem

$$\begin{aligned} \underset{z}{\text{maximize}} \quad & p(z \mid y) \\ \text{subject to} \quad & c(z) = 0 \end{aligned}$$

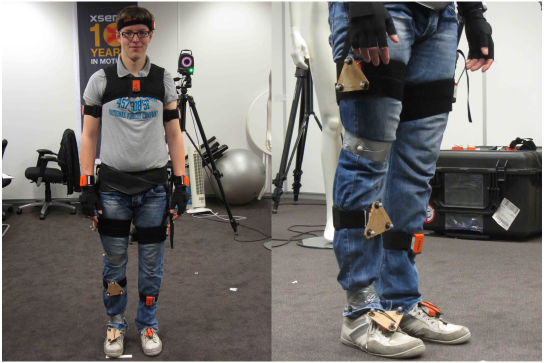
- Post-process data to obtain smoothing estimate.
- Natural inclusion of constraints.
- Naturally handles non-linearities.

Solving the inertial motion capture problem

$$\begin{aligned} \underset{z}{\text{maximize}} \quad & p(z \mid y) \\ \text{subject to} \quad & c(z) = 0 \end{aligned}$$

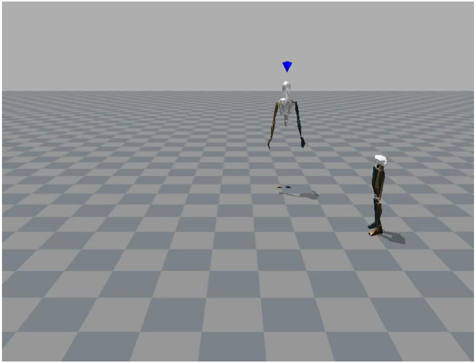
- Post-process data to obtain smoothing estimate.
- Natural inclusion of constraints.
- Naturally handles non-linearities.
- Problem is nonlinear $\Rightarrow$ Solve using sequential quadratic programming (SQP).

Previous results



Manon Kok, Jeroen D. Hol and Thomas B. Schön, An optimization-based approach to human body motion capture using inertial sensors. Proceedings of the 19th World Congress of the International Federation of Automatic Control (IFAC), pp. 79-85, Cape Town, South Africa, August 2014.

Previous results



Manon Kok, Jeroen D. Hol and Thomas B. Schön, An optimization-based approach to human body motion capture using inertial sensors. Proceedings of the 19th World Congress of the International Federation of Automatic Control (IFAC), pp. 79-85, Cape Town, South Africa, August 2014.

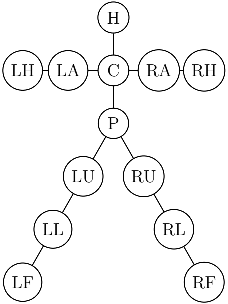
The inertial motion capture problem

The inertial motion capture problem is a large problem growing with

- the number of sensors,
- the number of body segments,
- and time.

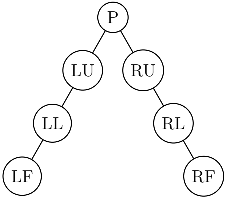
However, its structure is very sparse.

Structure of the problem



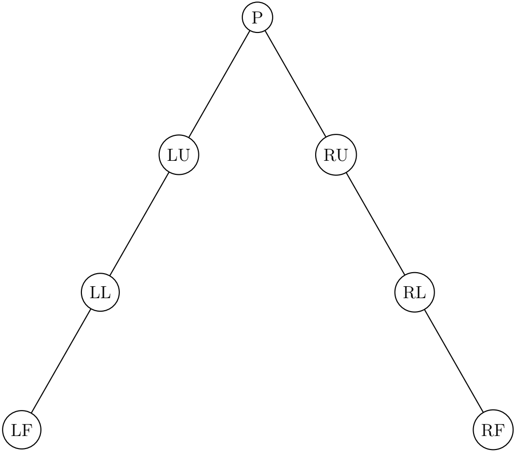
Structure of the problem

Focus on lower body



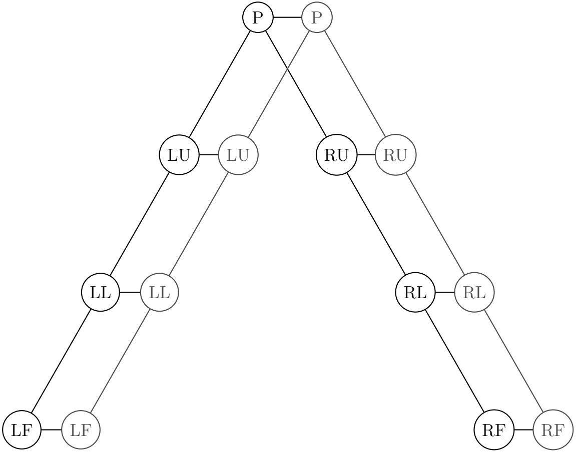
Structure of the problem

$t = 1$



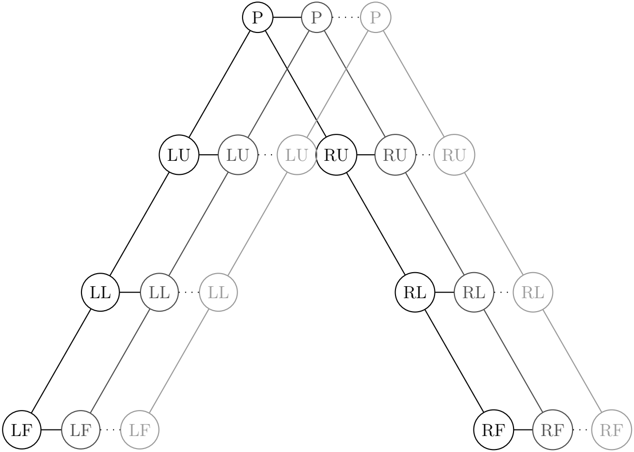
Structure of the problem

$t = 1$
$t = 2$



Structure of the problem

$t = 1$
$t = 2$
$\vdots$
$t = N_T$



Exploiting the structure of the problem

1. Exploit the structure over time …

Exploiting the structure of the problem

1. Exploit the structure over time ...
   - attack the problem by solving a large number of small problems.

Exploiting the structure of the problem

1. Exploit the structure over time …
   - attack the problem by solving a large number of small problems.
   - This enables us to process long data sets

Exploiting the structure of the problem

1. Exploit the structure over time ...
   - attack the problem by solving a large number of small problems.
   - This enables us to process long data sets
     - by reducing computational complexity,

Exploiting the structure of the problem

1. Exploit the structure over time ...
   - attack the problem by solving a large number of small problems.
   - This enables us to process long data sets
     - by reducing computational complexity,
     - by reducing the memory requirements because we have relaxed the need for even forming the complete smoothing problem.

Exploiting the structure of the problem

1. Exploit the structure over time …
   - attack the problem by solving a large number of small problems.
   - This enables us to process long data sets
     - by reducing computational complexity,
     - by reducing the memory requirements because we have relaxed the need for even forming the complete smoothing problem.
2. Exploit the structure over sensors / segments …

Exploiting the structure of the problem

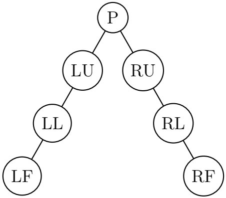
1. Exploit the structure over time ...
   - attack the problem by solving a large number of small problems.
   - This enables us to process long data sets
     - by reducing computational complexity,
     - by reducing the memory requirements because we have relaxed the need for even forming the complete smoothing problem.
2. Exploit the structure over sensors / segments ...
   - to allow for solving the problem distributedly using the sensors on the body,

Exploiting the structure of the problem

1. Exploit the structure over time ...
   - attack the problem by solving a large number of small problems.
   - This enables us to process long data sets
     - by reducing computational complexity,
     - by reducing the memory requirements because we have relaxed the need for even forming the complete smoothing problem.
2. Exploit the structure over sensors / segments ...
   - to allow for solving the problem distributedly using the sensors on the body,
   - which also relaxes the need for a centralized unit and streaming of data to it.

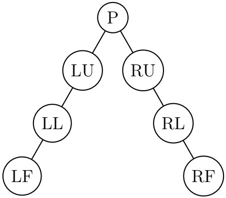
Structure of the problem

Structure over sensors / body segments

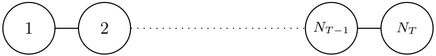


Structure of the problem

Structure over sensors / body segments

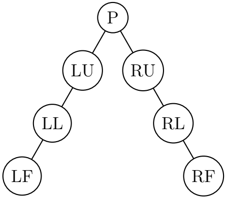


Structure over time

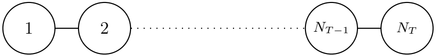


Structure of the problem

Structure over sensors / body segments



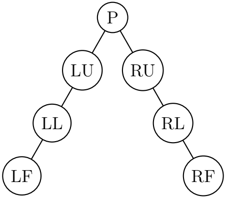
Structure over time



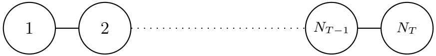
These graphs have an inherent tree structure and can be represented using a clique tree.

Cliques and clique tree

Structure over sensors / body segments

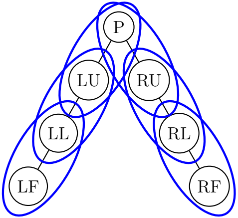


Structure over time

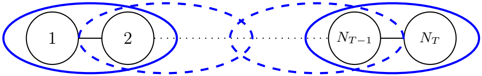


Cliques and clique tree

Structure over sensors / body segments

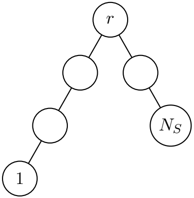


Structure over time

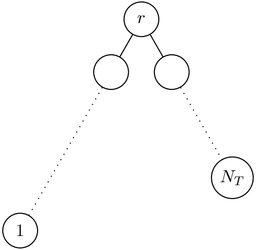


Cliques and clique tree

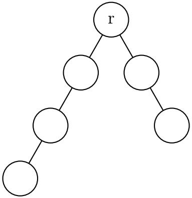
Structure over sensors / body segments



Structure over time

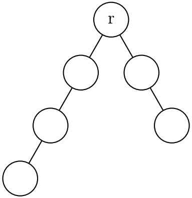


Message passing



Sina Khoshfetrat Pakazad, Anders Hansson, and Martin S. Andersen, Distributed primal-dual interior-point methods for solving loosely coupled problems using message passing, ArXiv e-prints, June 2015, arXiv:1502.06384.

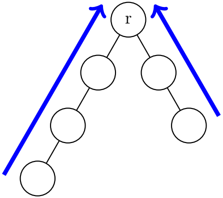
Message passing



An upward and downward pass computes the search direction for each SQP iteration.

Sina Khoshfetrat Pakazad, Anders Hansson, and Martin S. Andersen, Distributed primal-dual interior-point methods for solving loosely coupled problems using message passing, ArXiv e-prints, June 2015, arXiv:1502.06384.

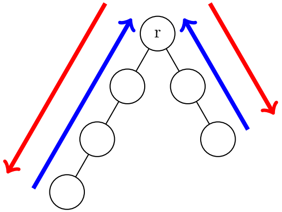
Message passing



An upward and downward pass computes the search direction for each SQP iteration.

Sina Khoshfetrat Pakazad, Anders Hansson, and Martin S. Andersen, Distributed primal-dual interior-point methods for solving loosely coupled problems using message passing, ArXiv e-prints, June 2015, arXiv:1502.06384.

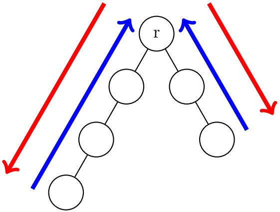
Message passing



An upward and downward pass computes the search direction for each SQP iteration.

Sina Khoshfetrat Pakazad, Anders Hansson, and Martin S. Andersen, Distributed primal-dual interior-point methods for solving loosely coupled problems using message passing, ArXiv e-prints, June 2015, arXiv:1502.06384.

Message passing



An upward and downward pass computes the search direction for each SQP iteration.

No approximations are made.

Sina Khoshfetrat Pakazad, Anders Hansson, and Martin S. Andersen, Distributed primal-dual interior-point methods for solving loosely coupled problems using message passing, ArXiv e-prints, June 2015, arXiv:1502.06384.

Results

37.3 seconds @ 10 Hz
7 sensors
7 body segments
$\Rightarrow$ 40305 variables and 6714 constraints

Results

37.3 seconds @ 10 Hz
7 sensors
7 body segments
$\Rightarrow$ 40305 variables and 6714 constraints

Exploiting structure in time: Solve 373 significantly smaller subproblems.

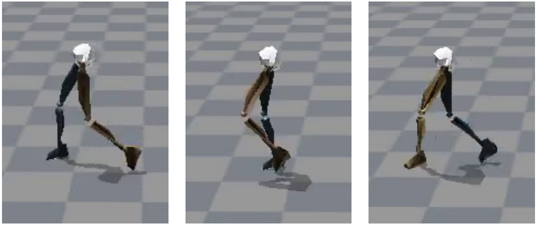
Results

37.3 seconds @ 10 Hz
7 sensors
7 body segments
$\Rightarrow$ 40305 variables and 6714 constraints

Exploiting structure in time: Solve 373 significantly smaller subproblems.

Exploiting structure in sensors / body segments: Solve 6 subproblems.

Results



Exploiting structure in time: Solve 373 significantly smaller subproblems.

Exploiting structure in sensors / body segments: Solve 6 subproblems.

Conclusions:

Conclusions:

The structure in the inertial motion capture problem can be exploited to allow for

Conclusions:

The structure in the inertial motion capture problem can be exploited to allow for

- processing long data sets by reducing computational complexity and memory requirements (**time**),

Conclusions:

The structure in the inertial motion capture problem can be exploited to allow for

- processing long data sets by reducing computational complexity and memory requirements (**time**),
- solving the problem distributedly using the sensors on the body (**sensors / body segments**).

Conclusions:

The structure in the inertial motion capture problem can be exploited to allow for

- processing long data sets by reducing computational complexity and memory requirements (**time**),
- solving the problem distributedly using the sensors on the body (**sensors / body segments**).

Shown proof of principle on experimental data from a lower body.

Conclusions:

The structure in the inertial motion capture problem can be exploited to allow for

- processing long data sets by reducing computational complexity and memory requirements (**time**),
- solving the problem distributedly using the sensors on the body (**sensors** / **body segments**).

Shown proof of principle on experimental data from a lower body.

Future work:

- Use the algorithm to solve full body problem.
- Apply the message passing algorithm to other problems having a similar structure.

Conclusions:

The structure in the inertial motion capture problem can be exploited to allow for

- processing long data sets by reducing computational complexity and memory requirements (**time**),
- solving the problem distributedly using the sensors on the body (**sensors** / **body segments**).

Shown proof of principle on experimental data from a lower body.

Thank you for your attention!

Questions?

`http://users.isy.liu.se/en/rt/manko/`