On the Design of Effective Modular Reconfigurable Grippers: an Iterative Approach

Candidate: Filippo Sanfilippo

Supervisor: Prof. Domenico Prattichizzo

Co-supervisors:
Eng. Gionata Salvietti
Prof. Jianwei Zhang
Prof. Houxiang Zhang

Academic year 2009/2010

University of Siena

April 29th, 2011
A collaboration between SIRSLab and TAMS Group
Main Contributions

- An algorithm capable of determining efficient modular gripper configurations to get a stable grasp of given objects;
- two real grippers obtained using the design algorithm;
- a simple planar manipulator model controlled drawing inspiration from the concept of human postural synergies.
Main Contributions

- An algorithm capable of determining efficient modular gripper configurations to get a stable grasp of given objects;
- two real grippers obtained using the design algorithm;
- a simple planar manipulator model controlled drawing inspiration from the concept of human postural synergies.
Main Contributions

- An algorithm capable of determining efficient modular gripper configurations to get a stable grasp of given objects;
- two real grippers obtained using the design algorithm;
- a simple planar manipulator model controlled drawing inspiration from the concept of human postural synergies.
Main Idea and Goal

Filippo Sanfilippo

On the Design of Effective Modular Reconfigurable Grippers
History and State of the Art

- simple actuated units;
- additional specialized units such as grippers, feet, wheels, cameras, ...

<table>
<thead>
<tr>
<th>System</th>
<th>Class, DOF</th>
<th>Author</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>PolyBot</td>
<td>chain, 1 3D</td>
<td>Yim et al. (PARC)</td>
<td>1998</td>
</tr>
<tr>
<td>Atron</td>
<td>lattice, 1 3D</td>
<td>Stoy et al., (U.S Denmark)</td>
<td>2003</td>
</tr>
<tr>
<td>Superbot</td>
<td>hybrid, 3 3D</td>
<td>Shen et al., (USC/ISI)</td>
<td>2004</td>
</tr>
<tr>
<td>M-TRAN III</td>
<td>hybrid, 2 3D</td>
<td>Kurokawa et al., (AIST)</td>
<td>2005</td>
</tr>
<tr>
<td>GZ-I Modules</td>
<td>Chain, 1 3D</td>
<td>Zhang &amp; Gonzalez-Gomez (TAMS, UAM)</td>
<td>2006</td>
</tr>
</tbody>
</table>
simple actuated units;

additional specialized units such as grippers, feet, wheels, cameras, ...

<table>
<thead>
<tr>
<th>System</th>
<th>Class, DOF</th>
<th>Author</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>PolyBot</td>
<td>chain, 1 3D</td>
<td>Yim et al. (PARC)</td>
<td>1998</td>
</tr>
<tr>
<td>Atron</td>
<td>lattice, 1 3D</td>
<td>Stoy et al., (U.S Denmark)</td>
<td>2003</td>
</tr>
<tr>
<td>Superbot</td>
<td>hybrid, 3 3D</td>
<td>Shen et al., (USC/ISI)</td>
<td>2004</td>
</tr>
<tr>
<td>M-TRAN III</td>
<td>hybrid, 2 3D</td>
<td>Kurokawa et al., (AIST)</td>
<td>2005</td>
</tr>
<tr>
<td>GZ-I Modules</td>
<td>Chain, 1 3D</td>
<td>Zhang &amp; Gonzalez-Gomez (TAMS, UAM)</td>
<td>2006</td>
</tr>
</tbody>
</table>
Previous Research on Modular Robot Design

There are many studies on kinematics, dynamic, and control design of modular robots. Three levels of modular robot architecture can be recognized:

- Module-level;
- Assembly-level;
- Configuration-level.

Our approach

We propose a new algorithm that involves all the three levels of modular robot architecture.
There are many studies on kinematics, dynamic, and control design of modular robots. Three levels of modular robot architecture can be recognized:

- Module-level;
- Assembly-level;
- Configuration-level.

Our approach

We propose a new algorithm that involves all the three levels of modular robot architecture.
Previous Research on Modular Robot Design

There are many studies on kinematics, dynamic, and control design of modular robots. Three levels of modular robot architecture can be recognized:

- Module-level;
- Assembly-level;
- Configuration-level.

Our approach

We propose a new algorithm that involves all the three levels of modular robot architecture.
There are many studies on kinematics, dynamic, and control design of modular robots. Three levels of modular robot architecture can be recognized:

- Module-level;
- Assembly-level;
- Configuration-level.

Our approach

We propose a new algorithm that involves all the three levels of modular robot architecture.
There are many studies on kinematics, dynamic, and control design of modular robots. Three levels of modular robot architecture can be recognized:

- Module-level;
- Assembly-level;
- Configuration-level.

**Our approach**

We propose a new algorithm that involves all the three levels of modular robot architecture.
There are many studies on kinematics, dynamic, and control design of modular robots. Three levels of modular robot architecture can be recognized:

- Module-level;
- Assembly-level;
- Configuration-level.

Our approach

We propose a new algorithm that involves all the three levels of modular robot architecture.
About this Work
Introduction
Modular Gripper Design Algorithm. An Object-oriented Approach
Simulations and Experimental Results
A Real Implementation
Human Postural Synergies and Modular Grippers
Conclusion and Future work

The Idea

Modular Gripper Design Algorithm. The Idea

\[ Q_1 = 0.1270 > 0.1 \]
\[ Q_2 = 0.1127 \]

planer execution time = 47 s

\[ m = 3, f = 1 \]
Compute $f_{\text{min}}$:

$$\frac{m}{f_{\text{min}}} \leq M. \quad (1)$$

If the inequality is not satisfied, $f_{\text{min}}$ is incremented by one to avoid the insertion of more than $M$ modules into a finger.

**Base configurations.** We defined three kinds of base dispositions:

- no finger opposition base;
- circular base;
- i-opposable-thumbs base.

We also considered the possibility to change the distance between the slots where the fingers are placed on the base.
Modular Gripper Design Algorithm. Flow-chart

<table>
<thead>
<tr>
<th></th>
<th>Current num. of modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>(m)</td>
<td>(f)</td>
</tr>
<tr>
<td>(f)</td>
<td>Current num. of fingers</td>
</tr>
<tr>
<td>(M)</td>
<td>Maximum num. of mod. per finger</td>
</tr>
<tr>
<td>(f_{\text{min}})</td>
<td>Minimum num. of fingers</td>
</tr>
<tr>
<td>(Q_{\text{desired}})</td>
<td>Predefined desired grasp quality</td>
</tr>
</tbody>
</table>

**Compute** \(f_{\text{min}}\).

\[
\frac{m}{f_{\text{min}}} \leq M. \tag{1}
\]

If the inequality is not satisfied, \(f_{\text{min}}\) is incremented by one to avoid the insertion of more than \(M\) modules into a finger.

**Base configurations.** We defined three kinds of base dispositions:
- no finger opposition base;
- circular base;
- \(i\)-opposable-thumbs base.

We also considered the possibility to change the distance between the slots where the fingers are placed on the base.
Compute \( f_{\text{min}} \).

\[
\frac{m}{f_{\text{min}}} \leq M. \tag{1}
\]

If the inequality is not satisfied, \( f_{\text{min}} \) is incremented by one to avoid the insertion of more than \( M \) modules into a finger.

**Base configurations.** We defined three kinds of base dispositions:
- no finger opposition base;
- circular base;
- \( i \)-opposable-thumbs base.

We also considered the possibility to change the distance between the slots where the fingers are placed on the base.
**Launch planner.** A grasp planner is used in order to determine the grasps achievable with the current configuration. We used a forward solution that is implemented in “Openrave”.

**Evaluate grasp.** In literature, there are different methods for assessing the grasp quality. We used the quality criteria introduced by Ferrari and Canny. However, all the other solutions could be implemented and used in our algorithm.

\[
GWS = \text{ConvexHull} \left( \bigcup_{i=1}^{n} \{w_{i,1}, \ldots, w_{i,k}\} \right)
\]

In particular we used \(Q_{1}\), that is the radius of the largest inscribed sphere centered at the origin contained in the GWS.

---

Launch planner. A grasp planner is used in order to determine the grasps achievable with the current configuration. We used a forward solution that is implemented in “Openrave”.

Evaluate grasp. In literature, there are different methods for assessing the grasp quality. We used the quality criteria introduced by Ferrari and Canny. However, all the other solutions could be implemented and used in our algorithm.

\[ GWS = ConvexHull \left( \bigcup_{i=1}^{n} \{ w_{i,1}, \ldots, w_{i,k} \} \right) \]

In particular we used \( Q_1 \), that is the radius of the largest inscribed sphere centered at the origin contained in the GWS.

---

Figure: Steps of the algorithm (a) and effective configuration (b) for grasping a bottle of ketchup.

We chose $Q_{desired} = 0.1$ since this or a greater measure of quality corresponds to grasps that a human would consider “stable”.
**Best Achievable Configuration**

**Figure**: Steps of the algorithm (a) and best achievable configuration (b) for grasping a bottle of ketchup.
Grasping Other Objects or Sets of Objects

Figure: Minimum manipulator configurations for respectively grasping a glass (a), a phone (b), a book (c), a flask (d), a cup (e) and an aircraft model (f).
Figure: Gripper configurations for cubic (a) and cylindrical (b) objects.
Despite the simplicity of a modular manipulator model, with the increase in the number of its fingers and modules, it also becomes rival to the human hand in complexity.

- Modular manipulators can be very different from the human one.

- We explored the possibility of using the two dominant human pregrasp shapes \(^1\) called *eigengrasps* \(^2\) in order to control one of the gripper obtained using our design algorithm. While we found our choices to produce good results, the optimal choice of eigengrasps for non-human hands, as well as the choice of which eigengrasps to use for a particular task, are still open questions.

![Figure: The two dominant human eigengrasps.](image-url)

---


Despite the simplicity of a modular manipulator model, with the increase in the number of its fingers and modules, it also becomes rival to the human hand in complexity.

Modular manipulators can be very different from the human one.

We explored the possibility of using the two dominant human pregrasp shapes \(^1\) called eigengrasps \(^2\) in order to control one of the gripper obtained using our design algorithm. While we found our choices to produce good results, the optimal choice of eigengrasps for non-human hands, as well as the choice of which eigengrasps to use for a particular task, are still open questions.

---


---

Figure: The two dominant human eigengrasps.
Despite the simplicity of a modular manipulator model, with the increase in the number of its fingers and modules, it also becomes rival to the human hand in complexity.

Modular manipulators can be very different from the human one.

We explored the possibility of using the two dominant human pregrasp shapes 1 called *eigengraspers* 2 in order to control one of the gripper obtained using our design algorithm. While we found our choices to produce good results, the optimal choice of eigengrasps for non-human hands, as well as the choice of which eigengrasps to use for a particular task, are still open questions.

---


A Possible Gripper Model

Figure: Grasp of a glass performed using the proximal joints flexion (a) and the distal joints flexion eigengrasp (b) objects.
Conclusion

What we have done:

- An algorithm capable of determining effective configurations modular gripper configurations to get a stable grasp of given objects;
- two real grippers obtained using the design algorithm;
- a simple planar manipulator model controlled drawing inspiration from the human postural synergies.

Problems:

- complexity of the algorithm;
- nor task-oriented neither hand-oriented approach.
Conclusion

What we have done:

- An algorithm capable of determining effective configurations modular gripper configurations to get a stable grasp of given objects;
- Two real grippers obtained using the design algorithm;
- A simple planar manipulator model controlled drawing inspiration from the human postural synergies.

Problems:

- Complexity of the algorithm;
- Nor task-oriented neither hand-oriented approach.
Conclusion

What we have done:

- An algorithm capable of determining effective configurations modular gripper configurations to get a stable grasp of given objects;
- two real grippers obtained using the design algorithm;
- a simple planar manipulator model controlled drawing inspiration from the human postural synergies.

Problems:

- complexity of the algorithm;
- nor task-oriented neither hand-oriented approach.
Conclusion

What we have done:

- An algorithm capable of determining effective configurations modular gripper configurations to get a stable grasp of given objects;
- two real grippers obtained using the design algorithm;
- a simple planar manipulator model controlled drawing inspiration from the human postural synergies.

Problems:

- complexity of the algorithm;
- nor task-oriented neither hand-oriented approach.
Conclusion

What we have done:

- An algorithm capable of determining effective configurations modular gripper configurations to get a stable grasp of given objects;
- two real grippers obtained using the design algorithm;
- a simple planar manipulator model controlled drawing inspiration from the human postural synergies.

Problems:

- complexity of the algorithm;
- nor task-oriented neither hand-oriented approach.
Task-oriented Grasping

- We should also take into account the re-usability of a grasped object.
- Only the grasp evaluation phase has to be modified in order to use a task-oriented metric.\(^1\)

Hand-oriented Grasping

- At each iteration, once the current manipulator configuration is generated, the achievable eigengrasps have to be defined;
- A method for obtaining the optimal choice and mapping of human synergies for non-human hands is necessary;
- It is necessary to use an eigengrasps planner.

Task-oriented Grasping

- We should also take into account the re-usability of a grasped object.
- Only the grasp evaluation phase has to be modified in order to use a task-oriented metric.\(^1\)

Hand-oriented Grasping

- At each iteration, once the current manipulator configuration is generated, the achievable eigengrasps have to be defined;
- A method for obtaining the optimal choice and mapping of human synergies for non-human hands is necessary;
- It is necessary to use an eigengrasps planner.

---

Task-oriented Grasping

- We should also take into account the re-usability of a grasped object.
- Only the grasp evaluation phase has to be modified in order to use a task-oriented metric \(^1\).

Hand-oriented Grasping

- At each iteration, once the current manipulator configuration is generated, the achievable eigengrasps have to be defined;
- A method for obtaining the optimal choice and mapping of human synergies for non-human hands is necessary;
- It is necessary to use an eigengrasps planner.

---

Task-oriented Grasping

- We should also take into account the re-usability of a grasped object.
- Only the grasp evaluation phase has to be modified in order to use a task-oriented metric $^1$.

Hand-oriented Grasping

- At each iteration, once the current manipulator configuration is generated, the achievable eigengrasps have to be defined;
- A method for obtaining the optimal choice and mapping of human synergies for non-human hands is necessary;
- It is necessary to use an eigengrasps planner.

---

Future work

Task-oriented Grasping

- We should also take into account the re-usability of a grasped object.
- Only the grasp evaluation phase has to be modified in order to use a task-oriented metric \(^1\).

Hand-oriented Grasping

- At each iteration, once the current manipulator configuration is generated, the achievable eigengrasps have to be defined;
- A method for obtaining the optimal choice and mapping of human synergies for non-human hands is necessary;
- It is necessary to use an eigengrasps planner.

Thank you for your attention

I am very grateful to Prof. Domenico Prattichizzo, Eng. Gionata Salvietti and Prof. Houxiang Zhang for their support and their helpfullness.

I thank all my family, especially Mom and Dad. Thank you for your care, support and incomparable love. I am who I am, because of you. Thanks also to my sister Elisa and my brother Riccardo for having always been close to me.

A big thanks to my second big family in Siena, the University Chapel of St. Vigilio. Thank you all for the endless love that is still surrounding me.