Modular Robots for Rapid Development and Deployment of Custom Automation

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Robots enable a transition from hard to flexible automation

Hard automation
(LEGO Factory – Billund, Denmark)

Soft automation
(Pepperidge Farm Factory – Denver, Colorado)

Flexible automation
(Tesla Factory – Fremont, California)
Robots are increasingly deployed in industrial settings…

*Worldwide estimated operational stock of industrial robots*

Source: IFR World Robotics 2015
… but complexity leads to standard configurations

6/7-DoF Manipulators

Delta Mechanisms

SCARA Arms

“Industrial Robot” Google image search results
Current robots are highly capable, but have drawbacks

- Low Multi-Task Versatility
- Low Ease-of-use
- High Price

Source: Bishop & Associates Inc.

Avg. Industrial Robot Sales Price

Source: Bishop & Associates Inc.
Co-Bots widen appeal, but are overkill for many tasks

Rethink Robotics’ Baxter

Franka Emika’s Franka

Franka manipulator arm performing a pick-and-place task
Currently, custom robots are essentially hard automation

Trade-offs introduced by current starting points for automation options
Robots should capture benefits of all automation types + more

<table>
<thead>
<tr>
<th>Hard Automation</th>
<th>Soft Automation</th>
<th>Flexible Automation</th>
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<tbody>
<tr>
<td>Easy to use</td>
<td>Relatively fast development</td>
<td>Fast development</td>
</tr>
<tr>
<td>High production rate</td>
<td>Flexible w.r.t. variations</td>
<td>“Infinite” flexibility</td>
</tr>
<tr>
<td>Low cost per produced unit</td>
<td>Suitable for batch production</td>
<td>Make “anything”</td>
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<tr>
<td>Slow development</td>
<td>High investment into “general purpose” equipment</td>
<td>High investment</td>
</tr>
<tr>
<td>High initial investment</td>
<td>Relatively slow production rate</td>
<td>High cost per produced unit</td>
</tr>
<tr>
<td>Inflexible</td>
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Modular robotic building blocks help fill this automation gap

- **Hard Automation:**
  - Custom robots with low number of “targeted degrees-of-freedom”

- **Soft Automation:**
  - Rapid development/deployment/integration

- **Flexible Mechanical Automation:**
  - Agile-inspired hardware development
## X-Series Industrial Smart Actuator

### Dimensions
- X5-1: 43 mm x 110 mm x 73 mm, 15 mm hollow bore
- X5-4: 43 mm x 110 mm x 73 mm, 15 mm hollow bore
- X5-9: 43 mm x 110 mm x 73 mm, 15 mm hollow bore

### Mass
- X5-1: 315 g
- X5-4: 335 g
- X5-9: 360 g

### Actuation
- **X5-1**:
  - Peak torque: 2.5 Nm
  - Cont. torque: 1.3 Nm
  - Max speed: 95 rpm
- **X5-4**:
  - Peak torque: 7 Nm
  - Cont. torque: 4 Nm
  - Max speed: 35 rpm
- **X5-9**:
  - Peak torque: 13 Nm
  - Cont. torque: 9 Nm
  - Max speed: 15 rpm

### Power
- 18-50 V DC
  - Cont. current: 0.8 A @ 24 V
  - Peak Current: 2.4 A @ 24 V

### Communication
- 1 kHz (100 Mbps Ethernet, dual port: Daisy-chainable)

### Sensing
- Angular position (multi-turn absolute, +/- 4 turns)
- Angular velocity, Output torque
- 3-Axis accelerometer, 3-Axis gyro
- Temperature, Voltage, Current

### Angular resolution
- 0.005 deg

### Backlash
- +/- 0.25 deg

### API Support
- Matlab (Windows / Linux / OS X), Simulink (under consideration)
- ROS (Linux)
- C/C++ (Windows (planned) / Linux / OS X)
- Java (in development), Python (planned)
On-demand custom robots in hours, not months

Twenty-four minute manipulator
Modular building blocks increase versatility, decrease cost

New task requires more reach

- Bigger robot ($ >40K)
  vs.
- Change link ($ 40)

New task requires more payload

- Bigger robot ($ >40K)
  vs.
- Gas spring assist ($ 15)

Automated button press

- Arm w/ force sensor ($ 60K)
  vs.
- Targeted DoF ($ <5K)
Robust building blocks enable focus on high-level integration

Collaborative vision-based bin picking project
Versatility, decentralization enables automation of novel tasks

Collaborative actuator assembly

Autonomous plant stalk inspection

Tele-operated mobile base

Tensegrity-based manipulation

Legged robots
Modularity enables hands-on robot education

Carnegie Mellon University’s 16-384: Robot Kinematics and Dynamics class
Conclusion

• **Takeaway 1:**
  - Modular robots enable customization and agile robot development

• **Takeaway 2:**
  - Robust robotic building blocks enable focus on high-level tasks

• **Takeaway 3:**
  - Modular robots allow targeted automation of diverse tasks

**Modular robots decrease cost and increase appeal for automating new industries**