*"**Cap**io **Sen**sus" ~ To understand the senses*

We write software that gives robots more spatial intelligence.

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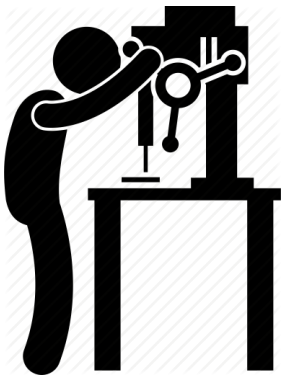
We need ***smarter*** robots

$620 billion

- U.S. labor cost / year on “physical work done in highly structured and predictable environments” that **could be automated** with “currently demonstrated technology.” *~ 2017 McKinsey study*



$2 billion

- 2018 U.S. robot sales

50 to 1

- Person-to-robot worker ratio in U.S. manufacturing (14 to 1 in S. Korea)

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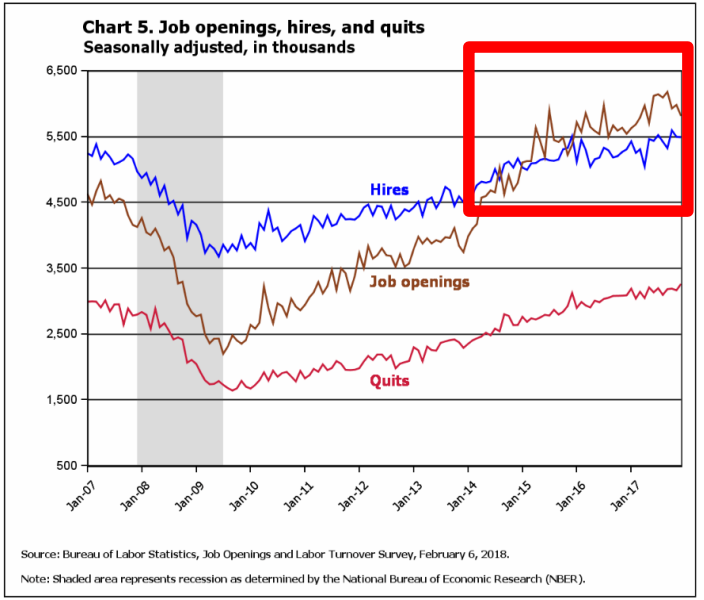
https://www.mckinsey.com/featured-insights/digital-disruption/harnessing-automation-for-a-future-that-works
https://ifr.org/ifr-press-releases/news/us-robot-density-now-more-than-double-that-of-china-ifr-says

We need smarter robots ***now***

- **Labor shortages due to:**
  - **3.5%** unemployment
  - **10,000** baby boomers reach retirement every day



- ***550,000*** *American manufacturing workers injured on the job in 2017* **(272 deaths)**

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https://www.mckinsey.com/featured-insights/digital-disruption/harnessing-automation-for-a-future-that-works
https://injuryfacts.nsc.org/work/work-overview/work-safety-introduction/

Hard jobs for robots

These tasks are:

- Physically demanding
- Extremely repetitive

But still require a great deal of spatial intelligence:

- Fine manipulations
- Hand-eye coordination
- Picking in clutter
- Operating machinery

https://drive.google.com/open?id=14SuiUOtyq7SjQO8P6obsjFPjQ5XPeWFO

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Our Solution

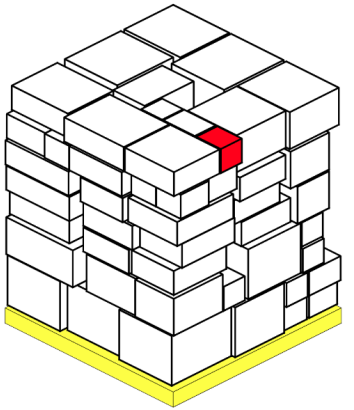
CapSen PiC™

3D vision software, full motion planning & control

- **Pick objects from clutter**
- **Precise placement** (position & orientation)
- **High-level task planning:**
  - Disentanglement
  - Stacking / Unstacking
- **Fast cycle time** (1 sec. image processing / planning)
- **Wide range of part sizes** (1 cm – 1 meter)
- **Works with any robot**
- **Supports multiple 3D cameras**

Bin Picking

Palletizing / Depalletizing



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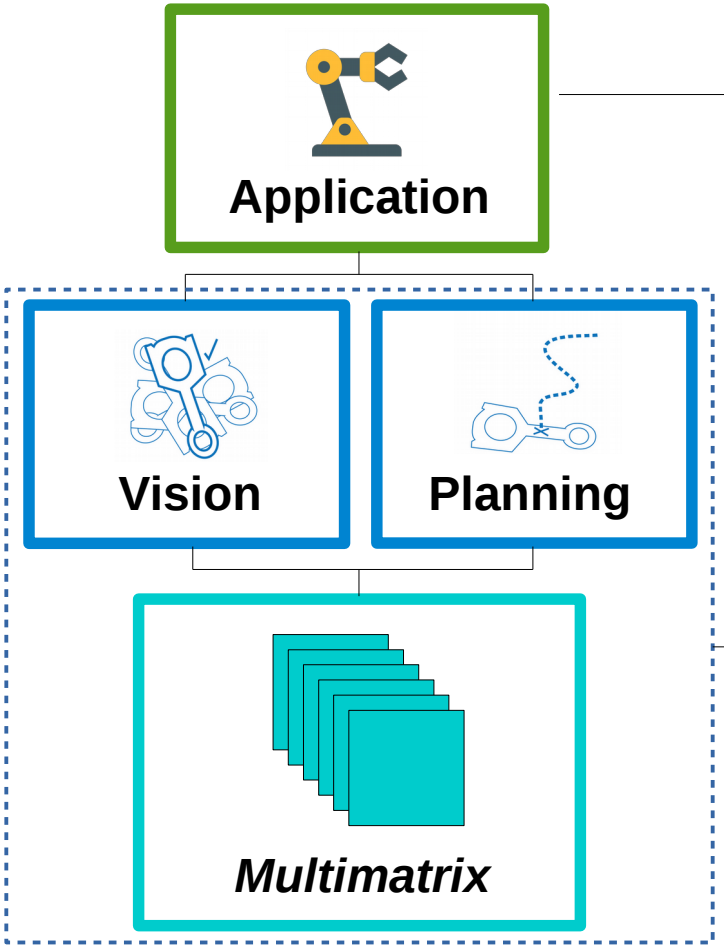
Our Platform



To meet your challenges, we offer:

- **Existing solutions**
  - Bin picking
  - Machine tending
  - Palletizing / Depalletizing
  - 3D Scanning / Object Recognition
- **Advanced R&D capabilities**
  - Custom systems for your needs

CapSen SDK
Extensive software infrastructure
Developed in-house

GPU-accelerated
Multimatrix—a CapSen-developed software library for parallel matrix computations

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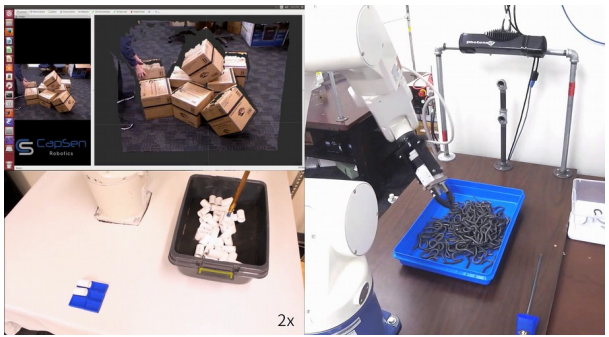
Our demo videos

Overview of CapSen capabilities
https://drive.google.com/open?id=1qKbHFjBaSNHpiKN-H0xRsexRuaslxVQI

Hook picking robot we recently installed at a wire & spring factory:
https://youtu.be/fcvulzMQ1kg



Picking springs:
https://photos.app.goo.gl/HbnLtW4mSVq5aVVY9

Picking screws:
https://drive.google.com/a/capsenrobotics.com/file/d/10JxloRsfS1YCitcN6QZymAZ9H-pHWesn/view

Picking bolts with a magnet:
https://drive.google.com/file/d/1Hz4MOgHcRHC2ZFT5UHKwjWE8OFvog1Kc

Picking bolts with fingers:
https://drive.google.com/open?id=1yBsN0STPLhlWTPqYK_BOx4ZtU-LfUZTM

Recent installations

Wire & Spring Manufacturer

- **Pick** hooks out of a bin and insert them into a press

Fortune 500 Nuclear Tech. Company

- **Scan** and **spray** objects the robot has never seen before

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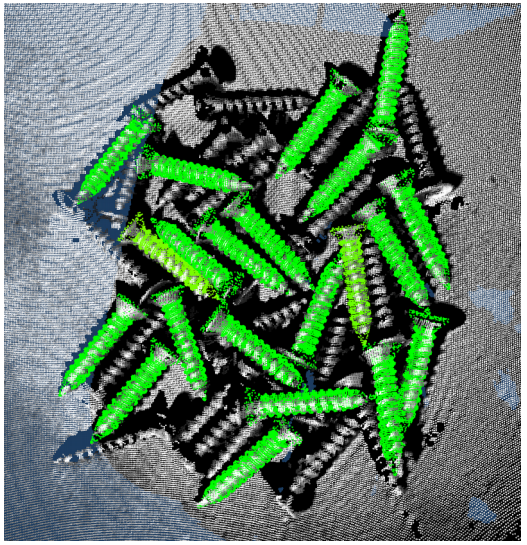
Competitive advantage

- Complete solution (vision + **motion planning** + control)
- **World's first entangled-part bin picking**
- Can detect & pick **very small parts** (screws, nuts, etc.)

- Multiple competitors in **bin picking**
- Most provide only vision + grasp analysis (not full motion planning)



- We're not a bin picking company...
  we're a spatial intelligence company

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Application #1

- Traditional manufacturer (80+ years)
- Experts at what they do
- Family business

ace wire spring & form co., inc.

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- **Rich (Ace Wire Spring):**
  Nobody likes doing this job.
  Can we use a robot?

CapSen ROBOTICS

- **Rich (Ace Wire Spring):**
  Nobody likes doing this job.
  Can we use a robot?

- **Jared (CapSen):**
  - *Random bin picking*
  - *Small, complex parts*
  - *Precise placements*
  - *Parts can get entangled!*
  - ***Never been done before…***

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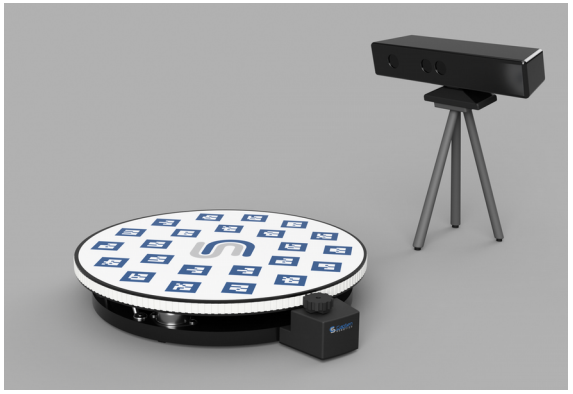
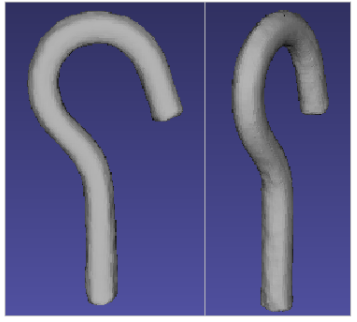
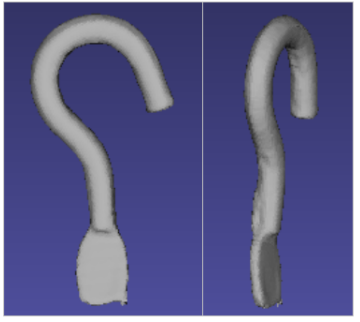
- **Step 1**
  Scan in 3D models of the objects to be picked







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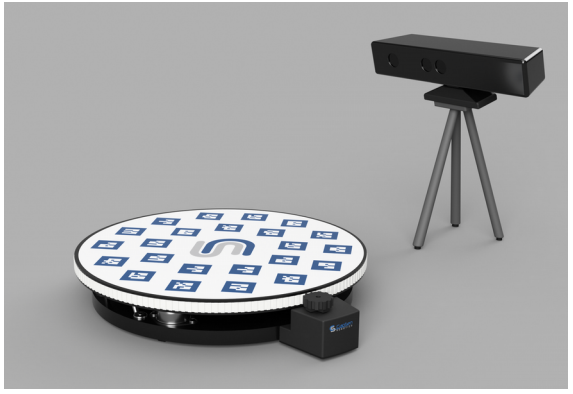
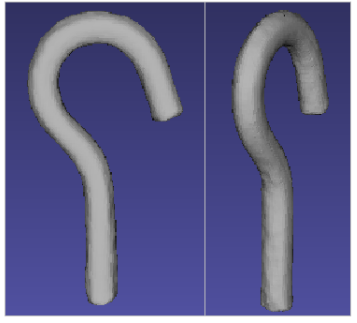
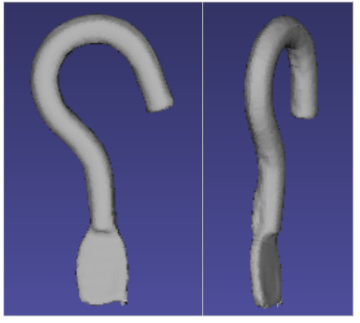
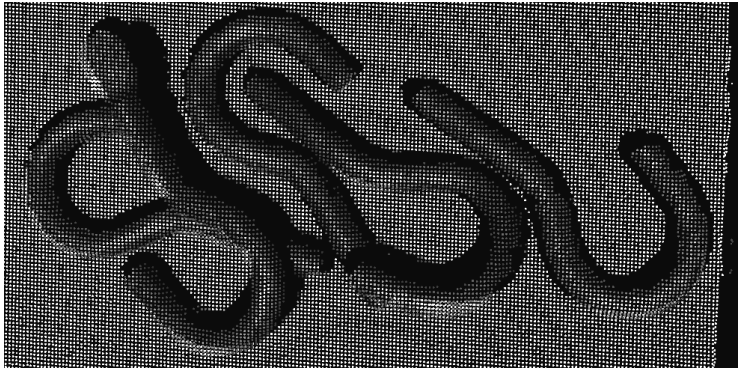
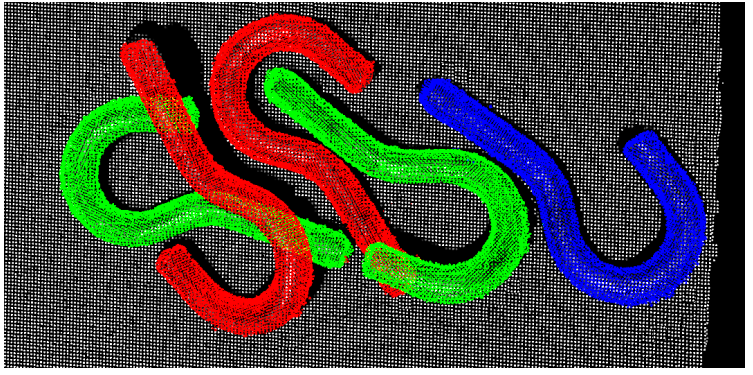






- **Step 2**
  Make sure our detection software can accurately locate the objects





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- **Step 2...**
  Make sure our detection software can accurately locate the objects

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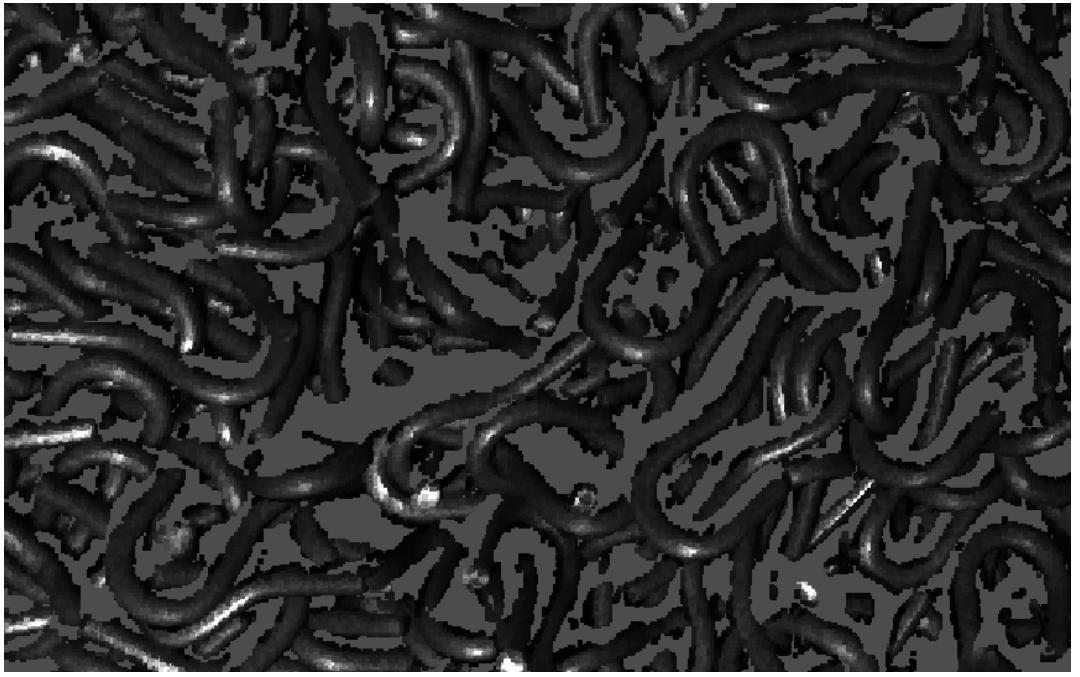
This is what the robot sees →



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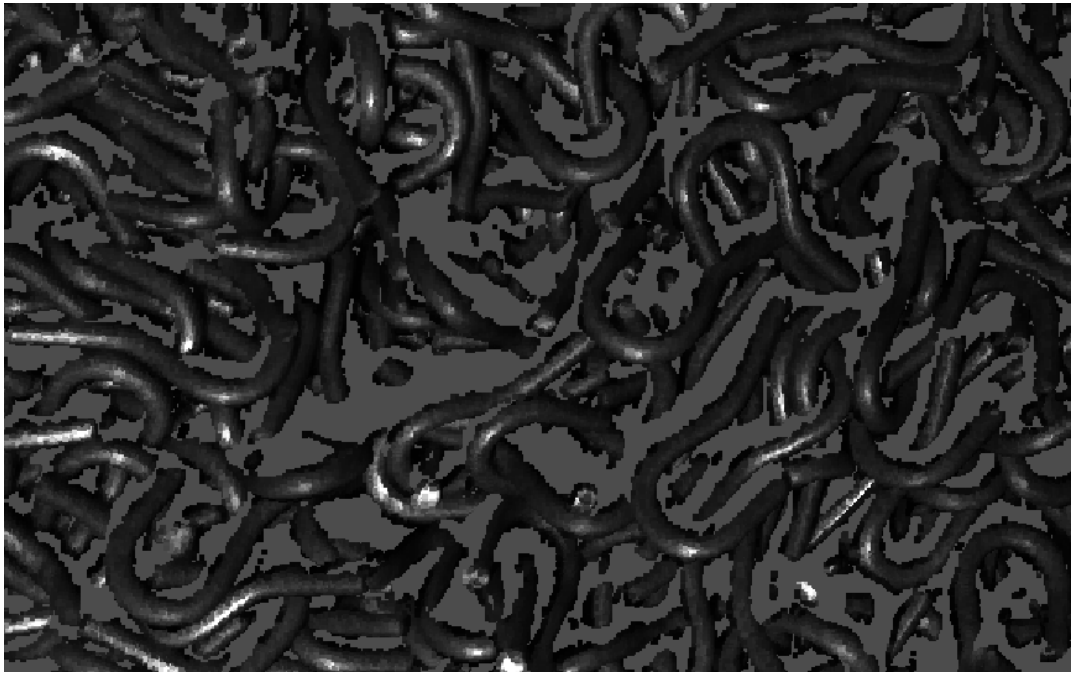
- **Step 2...**
  Make sure our detection software can accurately locate the objects

1. Select a 3D sensor

- PhoXi M



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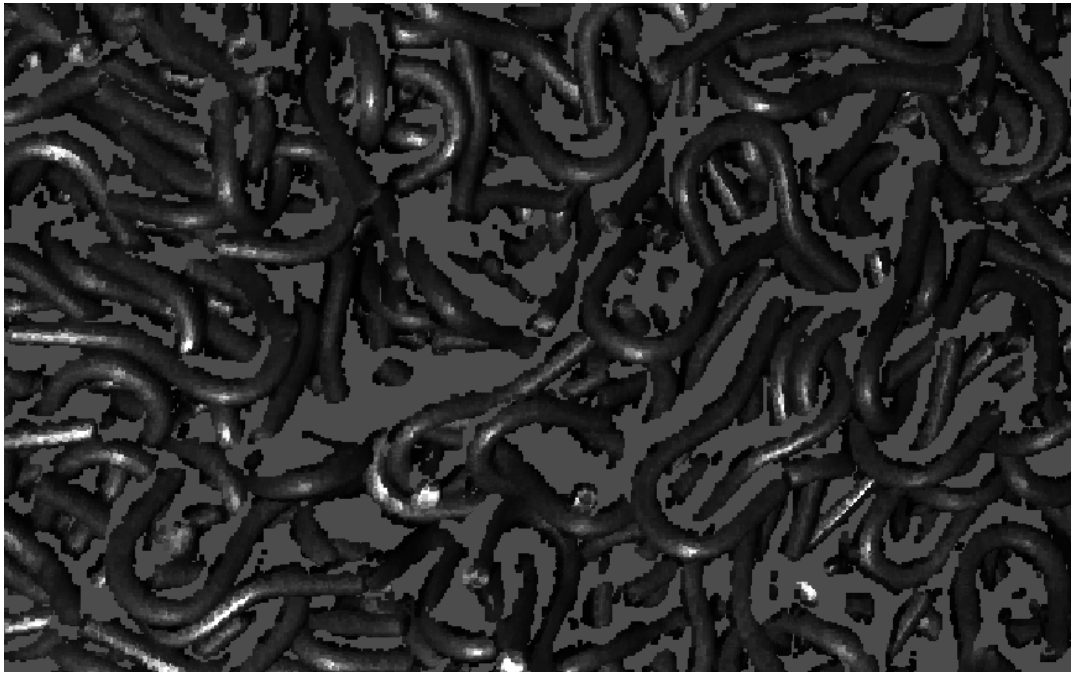
- **Step 2...**
  Make sure our detection software can accurately locate the objects

1. Select a 3D sensor

- PhoXi M

2. Tune sensor params

- Exposure times
- Proj. patterns (number & orientation)
- Noise filtering



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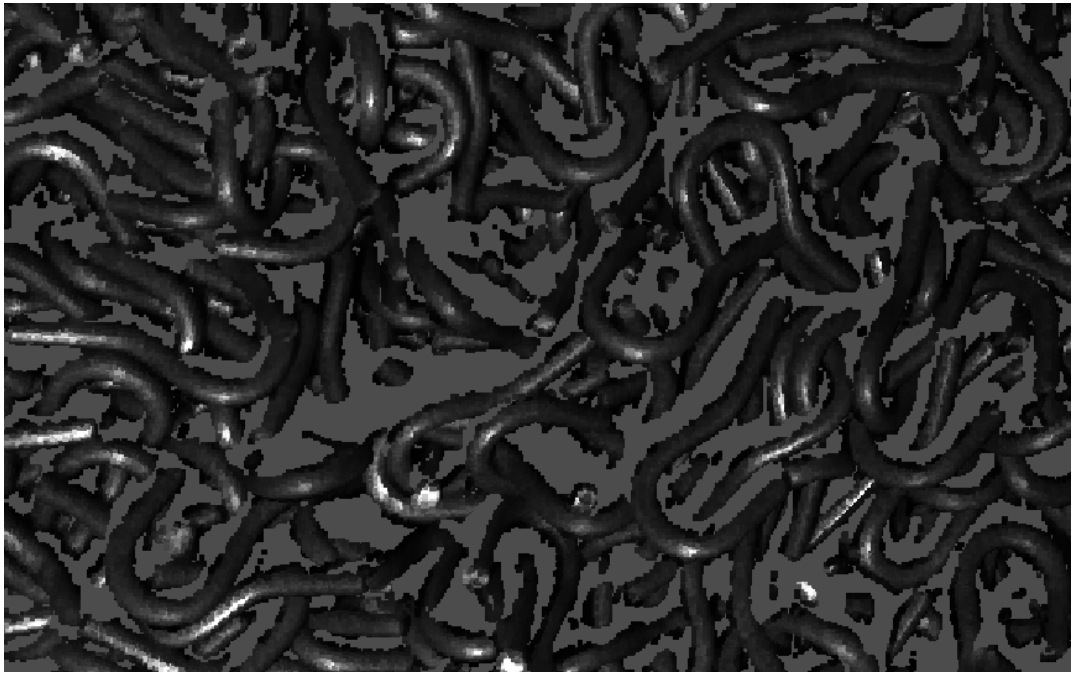
- # detections vs. processing time
- (Optional) Train a new ML model



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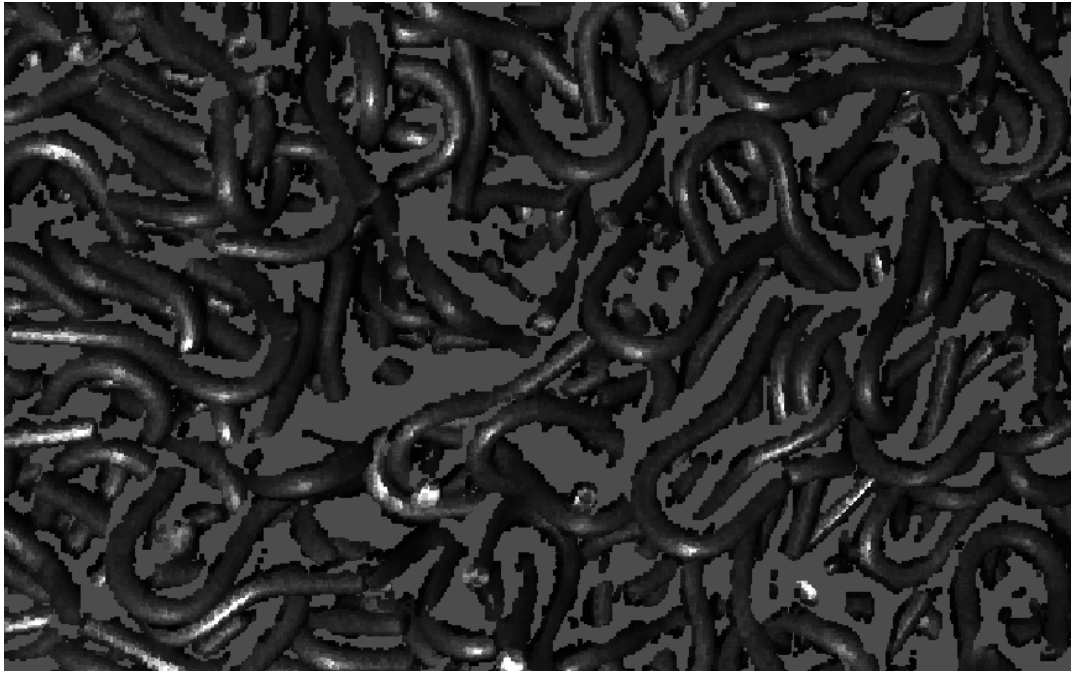

4. Test

- If not good enough, return to step 1, 2, or 3

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- **Step 3**

  Select a robot arm

PRECISE AUTOMATION

Repeatability: 30 microns

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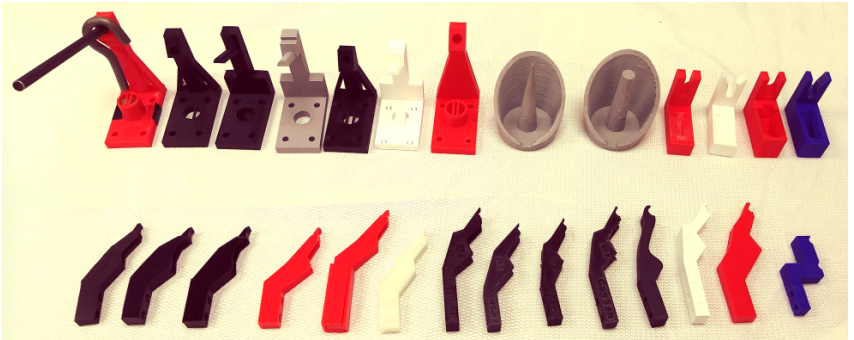
- **Step 3**
  Select a robot arm

Repeatability: 30 microns

- **Step 4**
  Design fingers & fixtures



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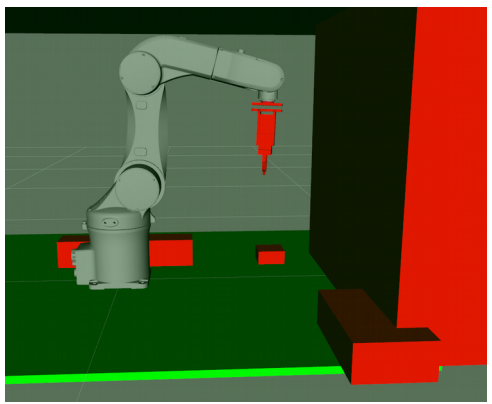
- **Step 5**
  Task configuration

	A	B	C	D	E	F	G	H	I	J	K
1	type	device name	description	wait_seconds	close_consistency	staging_offset	speed	constrained_radius	skip_first	num_attempts	gripper pos
2	light_on	Lightstack1	green on								
3	set_payload	Myrobot1									
4	gripper_pos	Gripper1	open	0							23
5	#move_link	Myrobot1	inactive pose		FALSE	0	1	FALSE	FALSE	1	
6	move_pick	Myrobot1	staging pose		FALSE	-0.05	1	FALSE	TRUE	1	
7	gripper_pos	Gripper1	half open	0							10
8	move_pick	Myrobot1	picking pose	0	TRUE	0	0.1	TRUE	TRUE	1	
9	sync_moves	Myrobot1									
10	ack_wait	Myrobot1									
11	gripper_pos	Gripper1	closed	0							24
12	move_pick	Myrobot1	staging pose		FALSE	-0.05	1	FALSE	TRUE	1	
13	move_link	Myrobot1	disentangle pose 1		FALSE	0	1	FALSE	TRUE	1	
14	move_link	Myrobot1	disentangle pose 2		FALSE	0	1	FALSE	TRUE	1	
15	move_link	Myrobot1	fixture drop pose 0		FALSE	0	1	FALSE	TRUE	1	
16	move_link	Myrobot1	fixture drop pose 1		FALSE	0	1	FALSE	TRUE	1	
17	move_link	Myrobot1	fixture drop pose 2		FALSE	0	0.3	FALSE	TRUE	1	
18	sync_moves	Myrobot1									
19	ack_wait	Myrobot1									
20	ack	Myrobot1									
21	gripper_pos	Gripper1	open	0							23
22	move_link	Myrobot1	fixture drop pose 1		FALSE	0	1	FALSE	TRUE	1	
23	move_joints	Myrobot1	fixture pick pose 0		FALSE	0	1	FALSE	TRUE	1	
24	move_joints	Myrobot1	fixture pick pose 1		FALSE	0	1	FALSE	TRUE	1	
25	sync_moves	Myrobot1									
26	ack_wait	Myrobot1									
27	ensure_dr	DIO1									
28	move_joints_direct	Myrobot1	fixture pick pose 2		FALSE	0	1	FALSE	TRUE	1	
29	move_joints_direct	Myrobot1	fixture pick pose 3		FALSE	0	1	FALSE	TRUE	1	
30	move_joints_direct	Myrobot1	fixture pick pose 4		FALSE	0	1	FALSE	TRUE	1	
31	sync_moves	Myrobot1									
32	ack_wait	Myrobot1									
33	gripper_pos	Gripper1	half open	0							10
34	move_joints_direct	Myrobot1	fixture pick pose 5		FALSE	0	1	FALSE	TRUE	1	
35	move_joints_direct	Myrobot1	fixture pick pose 6		FALSE	0	1	FALSE	TRUE	1	
36	move_joints	Myrobot1	verify pose 0		FALSE	0	1	FALSE	TRUE	1	
37	gripper_pos	Gripper1	closed 2	0							25
38	move_joints_direct	Myrobot1	press pose 1		FALSE	0	1	FALSE	TRUE	1	
39	move_joints_direct	Myrobot1	press pose 2		FALSE	0	0.1	FALSE	TRUE	1	
40	move_joints_direct	Myrobot1	press pose 1		FALSE	0	1	FALSE	TRUE	1	
41	move_joints_direct	Myrobot1	drop pose 1		FALSE	0	1	FALSE	TRUE	1	
42	sync_moves	Myrobot1									
43	ack_wait	Myrobot1									
44	gripper_pos	Gripper1	open	0							23
45	move_joints_direct	Myrobot1	drop pose 2		FALSE	0	1	FALSE	TRUE	1	
46	move_joints_direct	Myrobot1	drop pose 1		FALSE	0	1	FALSE	TRUE	1	
47	#move_link	Myrobot1	inactive pose		FALSE	0	1	FALSE	FALSE	1	



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- **Step 5**
  Task configuration

	A	B	C	D	E	F	G	H	I	J	K
1	type	device name	description	wait_seconds	close_consistency	staging_offset	speed	constrained_radius	skip_first	num_attempts	gripper pos
2	light_on	Lightstack1	green on								
3	set_payload	Mynobot1									
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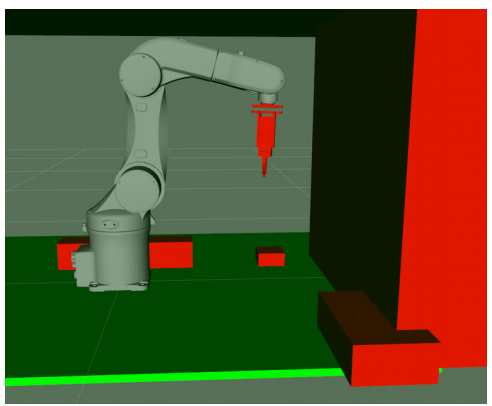
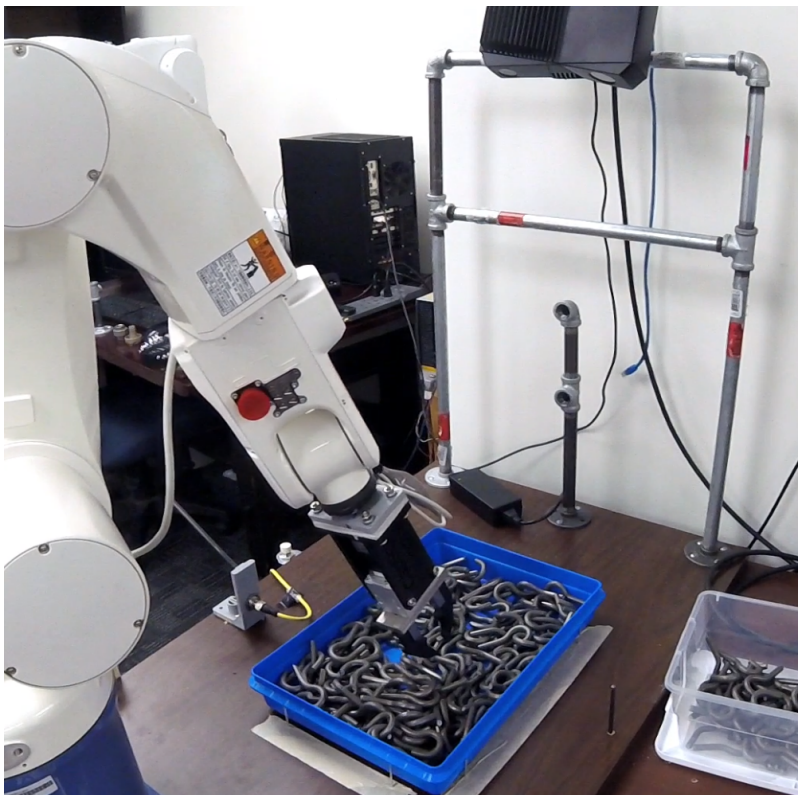
5	#move_link	Mynobot1	inactive pose		FALSE	0	1	FALSE	FALSE	1	
6	move_pick	Mynobot1	staging pose		FALSE	-0.05	1	FALSE	TRUE	1	
7	gripper_pos	Gripper1	half open	0							10
8	move_pick	Mynobot1	picking pose	0	TRUE	0	0.1	TRUE	TRUE	1	
9	sync_moves	Mynobot1									
10	ack_wait	Mynobot1									
11	gripper_pos	Gripper1	closed	0							24
12	move_pick	Mynobot1	staging pose		FALSE	-0.05	1	FALSE	TRUE	1	
13	move_link	Mynobot1	disentangle pose 1		FALSE	0	1	FALSE	TRUE	1	
14	move_link	Mynobot1	disentangle pose 2		FALSE	0	1	FALSE	TRUE	1	
15	move_link	Mynobot1	fixture drop pose 0		FALSE	0	1	FALSE	TRUE	1	
16	move_link	Mynobot1	fixture drop pose 1		FALSE	0	1	FALSE	TRUE	1	
17	move_link	Mynobot1	fixture drop pose 2		FALSE	0	0.3	FALSE	TRUE	1	
18	sync_moves	Mynobot1									
19	ack_wait	Mynobot1									
20	ack	Mynobot1									
21	gripper_pos	Gripper1	open	0							23
22	move_link	Mynobot1	fixture drop pose 1		FALSE	0	1	FALSE	TRUE	1	
23	move_joints	Mynobot1	fixture pick pose 0		FALSE	0	1	FALSE	TRUE	1	
24	move_joints	Mynobot1	fixture pick pose 1		FALSE	0	1	FALSE	TRUE	1	
25	sync_moves	Mynobot1									
26	ack_wait	Mynobot1									
27	ensure_dI	DIO1									
28	move_joints_direct	Mynobot1	fixture pick pose 2		FALSE	0	1	FALSE	TRUE	1	
29	move_joints_direct	Mynobot1	fixture pick pose 3		FALSE	0	1	FALSE	TRUE	1	
30	move_joints_direct	Mynobot1	fixture pick pose 4		FALSE	0	1	FALSE	TRUE	1	
31	sync_moves	Mynobot1									
32	ack_wait	Mynobot1									
33	gripper_pos	Gripper1	half open	0							10
34	move_joints_direct	Mynobot1	fixture pick pose 5		FALSE	0	1	FALSE	TRUE	1	
35	move_joints_direct	Mynobot1	fixture pick pose 6		FALSE	0	1	FALSE	TRUE	1	
36	move_joints	Mynobot1	verify pose 0		FALSE	0	1	FALSE	TRUE	1	
37	gripper_pos	Gripper1	closed 2	0							25
38	move_joints_direct	Mynobot1	press pose 1		FALSE	0	1	FALSE	TRUE	1	
39	move_joints_direct	Mynobot1	press pose 2		FALSE	0	0.1	FALSE	TRUE	1	
40	move_joints_direct	Mynobot1	press pose 1		FALSE	0	1	FALSE	TRUE	1	
41	move_joints_direct	Mynobot1	drop pose 1		FALSE	0	1	FALSE	TRUE	1	
42	sync_moves	Mynobot1									
43	ack_wait	Mynobot1									
44	gripper_pos	Gripper1	open	0							23
45	move_joints_direct	Mynobot1	drop pose 2		FALSE	0	1	FALSE	TRUE	1	
46	move_joints_direct	Mynobot1	drop pose 1		FALSE	0	1	FALSE	TRUE	1	
47	#move_link	Mynobot1	inactive pose		FALSE	0	1	FALSE	FALSE	1	



- **Step 6**
  Full system test @CapSen



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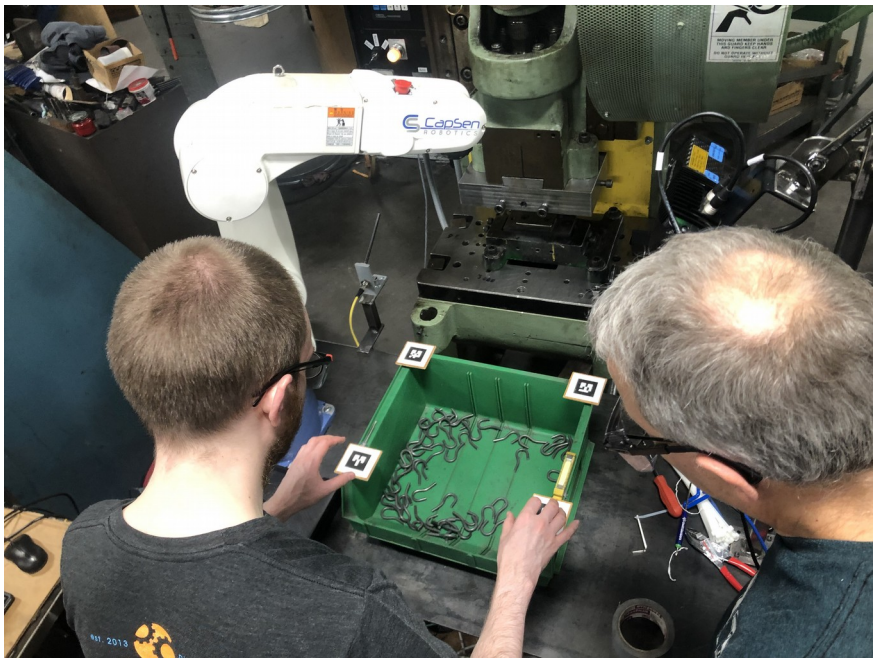
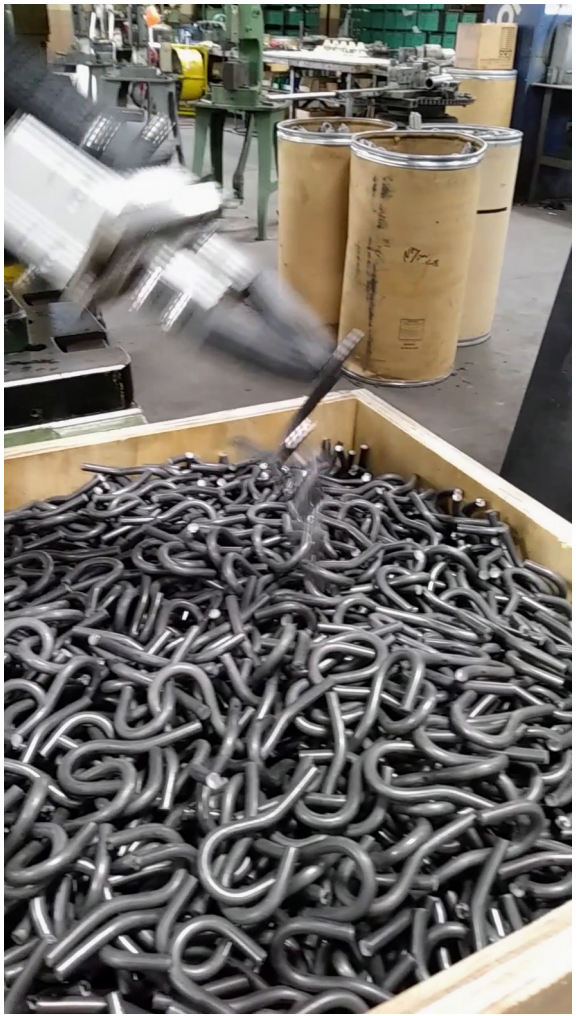
- **Step 7**
  Install @Ace





https://youtu.be/fcvulzMQ1kg

CapSen ROBOTICS

Application #2

Fortune 500 Nuclear Tech. Co.

- **Scan** and **spray** objects the robot has never seen before

CapSen ROBOTICS

Application #2

Fortune 500 Nuclear Tech. Co.

- **Scan** and **spray** objects the robot has never seen before

1. Some types of sensor noise are OK (multiple views are stitched together)

- Missing points
- Unbiased, Gaussian noise

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Application #2

Fortune 500 Nuclear Tech. Co.

- **Scan** and **spray** objects the robot has never seen before

1. Some types of sensor noise are OK (multiple views are stitched together)

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3. System failures:

- **Collision**
  (Due to missing object part)
- **Incomplete coverage**
  (Due to incorrect model shape)

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Lessons?

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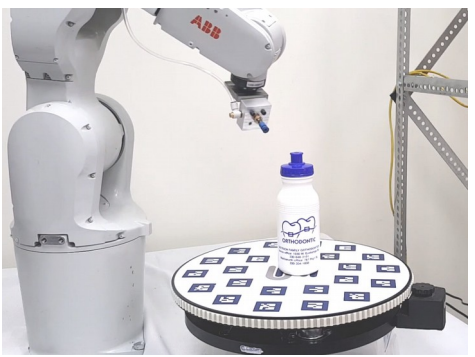
   - Require customization / parameter tuning of sensors & software for each installation



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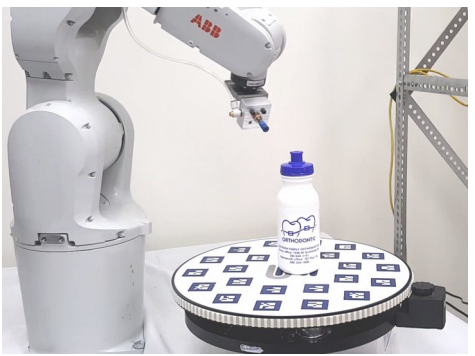
2. **Different applications can have vastly different performance metrics**
   - This argues for having many standards to choose from and/or complete end-to-end system testing



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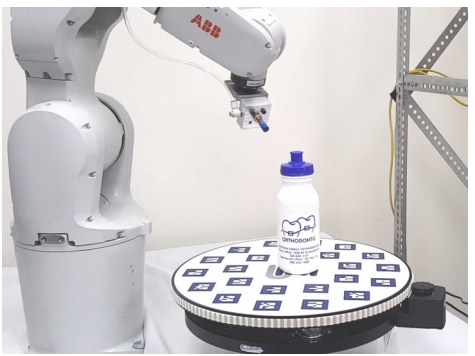

3. **Performance metrics depend on many inputs**
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