ME345: Automation & Manufacturing Methods

Lectures 11 & 12: Vision and Advanced Robotics and Integration

10/16/2023

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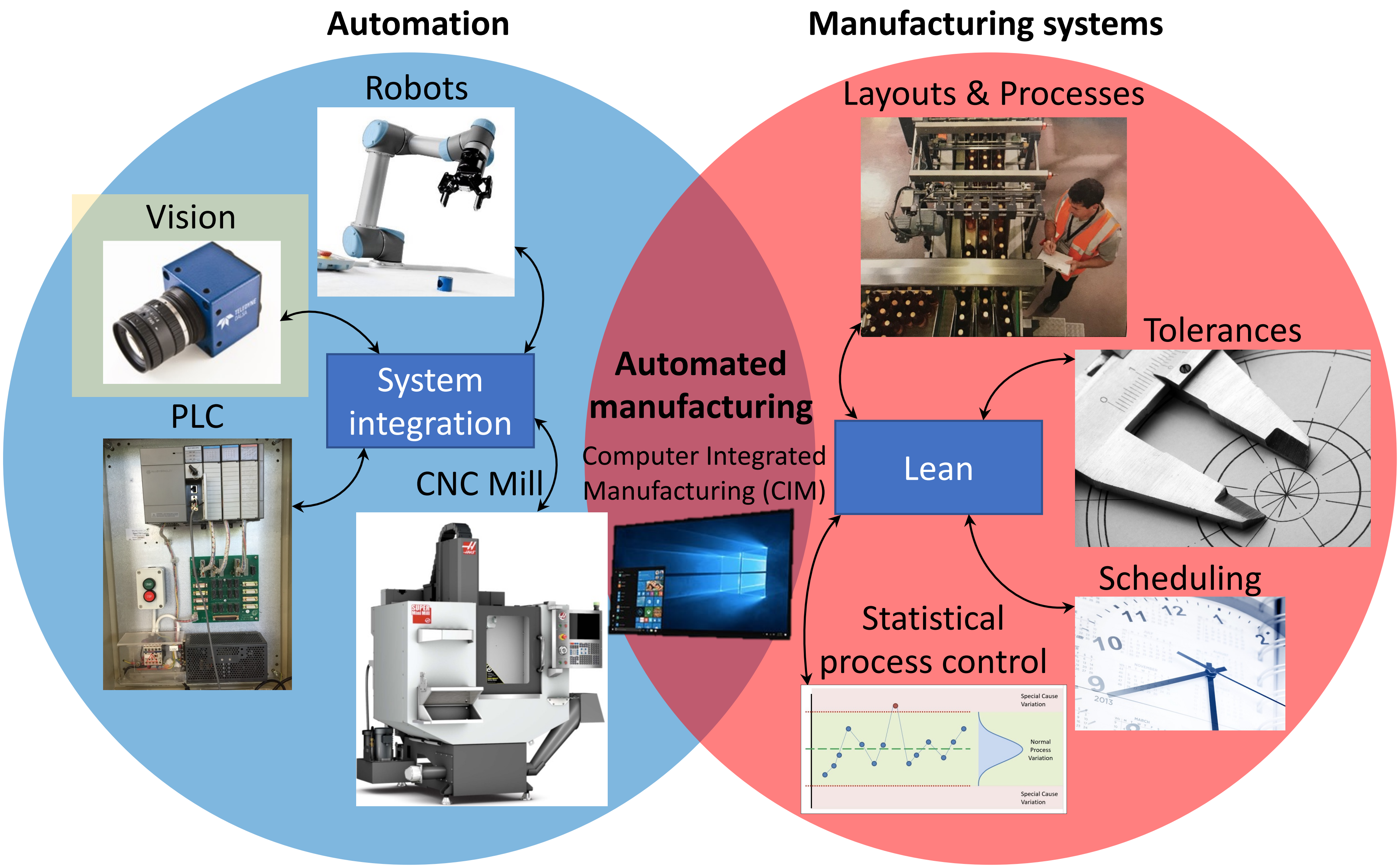
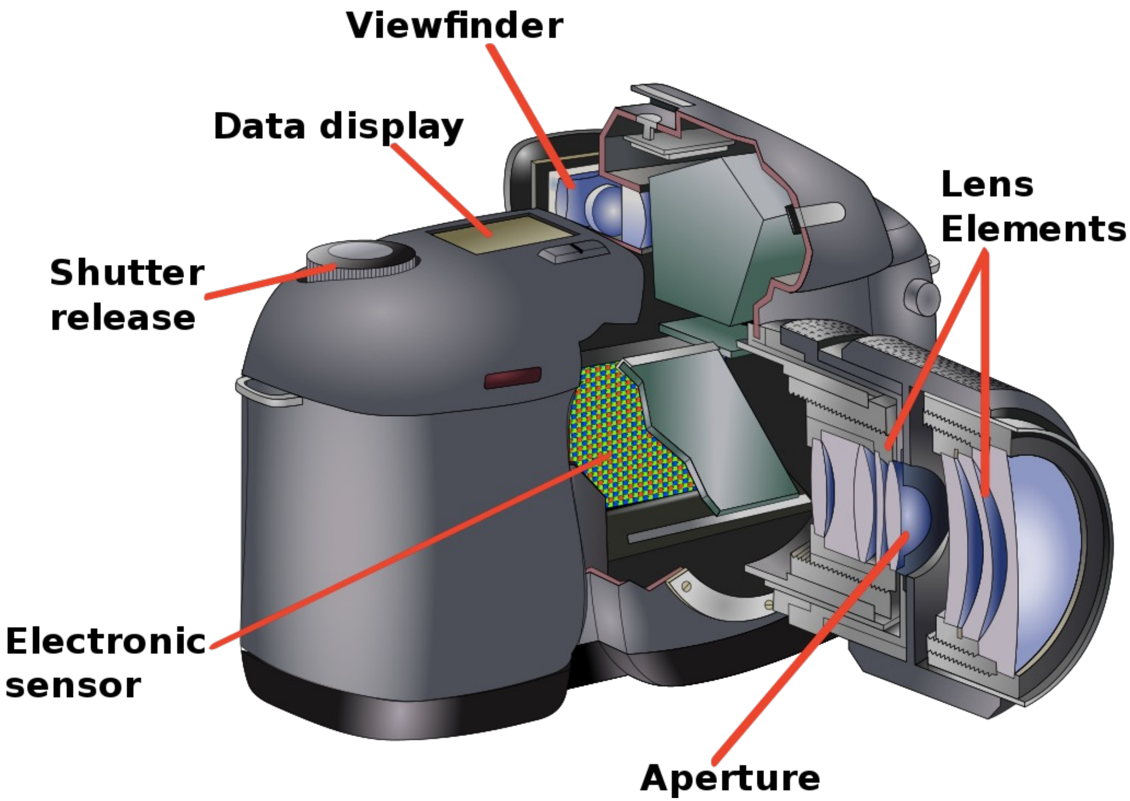
Assistant Professor, MechE, MSE

Course overview - Vision



Camera basics



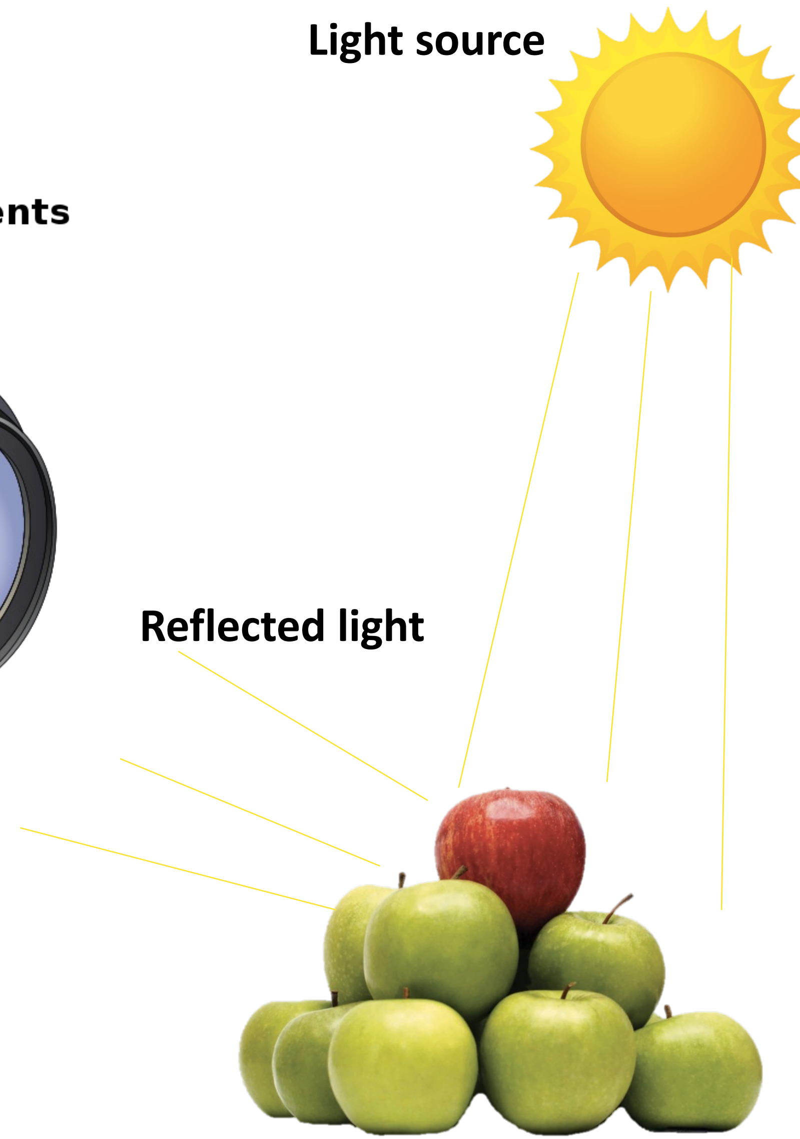
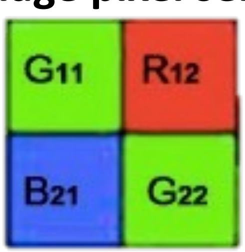
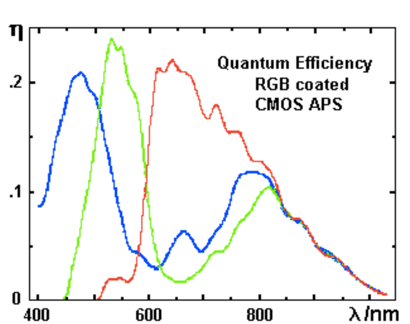


Image pixel sensor

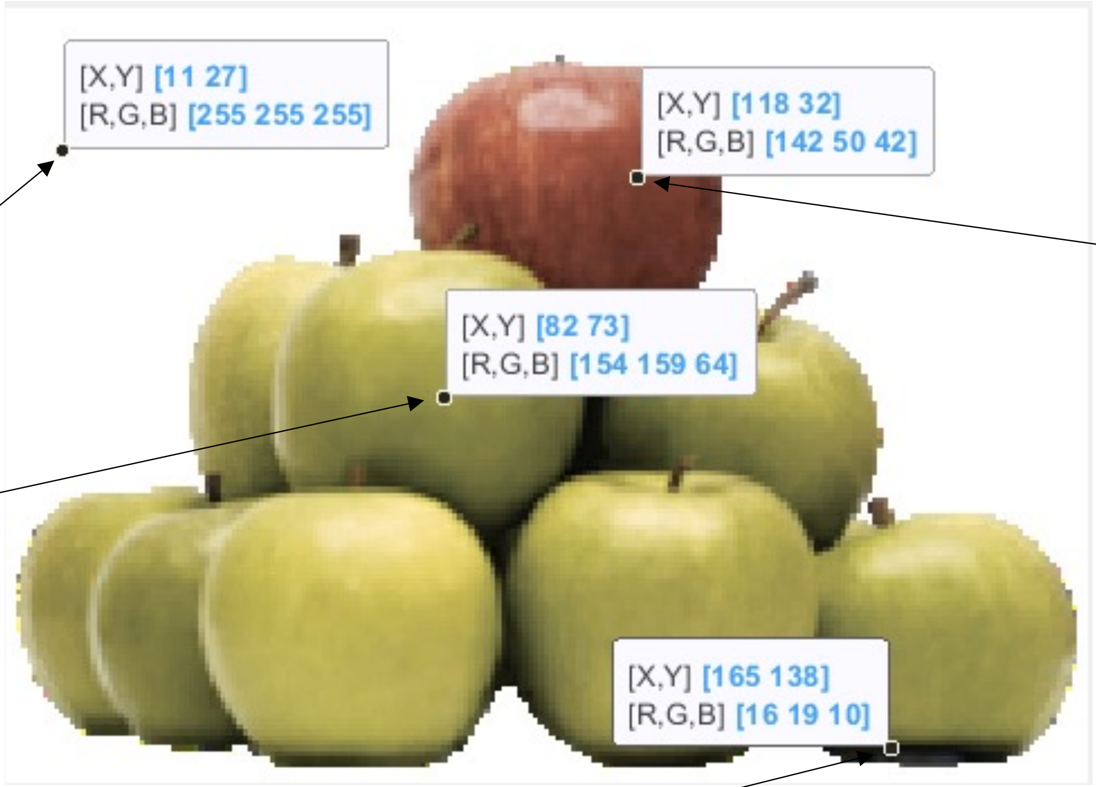




What does image data look like?

Displayed image with selected pixel data

white



mostly red

yellow green

close to black (shadow)

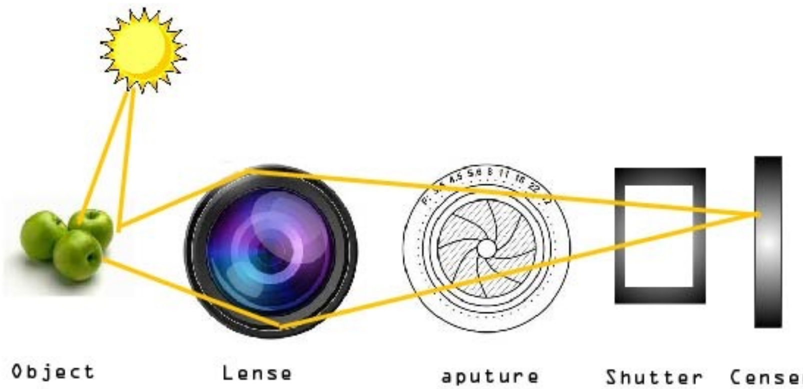
Image file read using Matlab

0-255 → 8 bit depth for each channel (RGB)

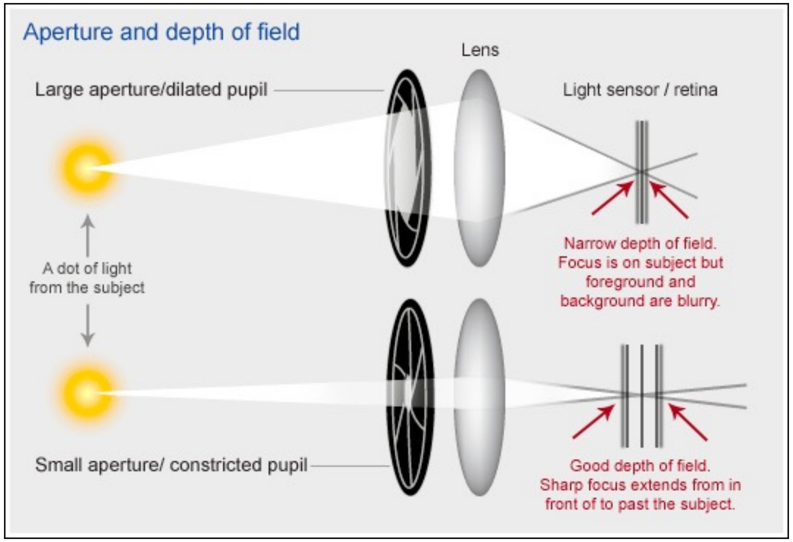
Vision Systems = Digital Photography

What are the key things you can control?

- Shutter speed
  - Controls amount of light (photons) collected [faster = less light]
- Aperture
  - Depth Of Field [larger aperture = smaller DOF]
  - Light (photons) collected [larger aperture = more light]
- Focus
  - Usually fixed in industrial settings, since cameras don't usually move
- Optical quality
  - Depends on quality/cost of camera
- Image processing speed
  - Depends on quality/cost camera



Source: https://aashishphotography.wordpress.com/2012/06/27/how-a-digital-camera-works/

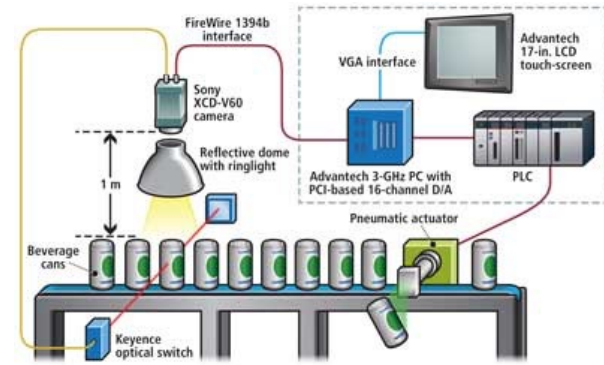


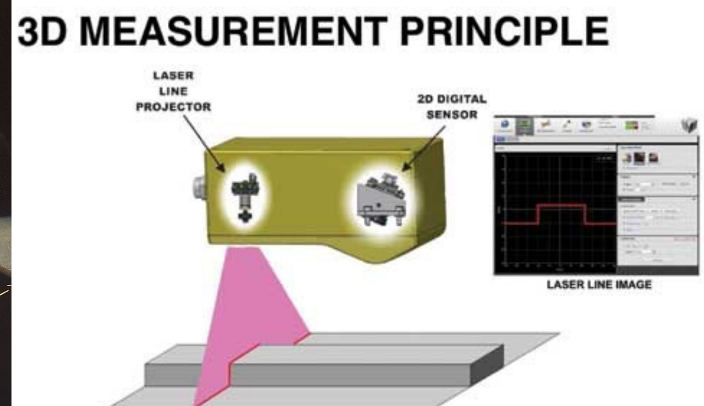
Source: http://www.abc.net.au/science/askanexpert/img/aperture.jpg

First Kahoot!

Machine Vision for Factory Automation

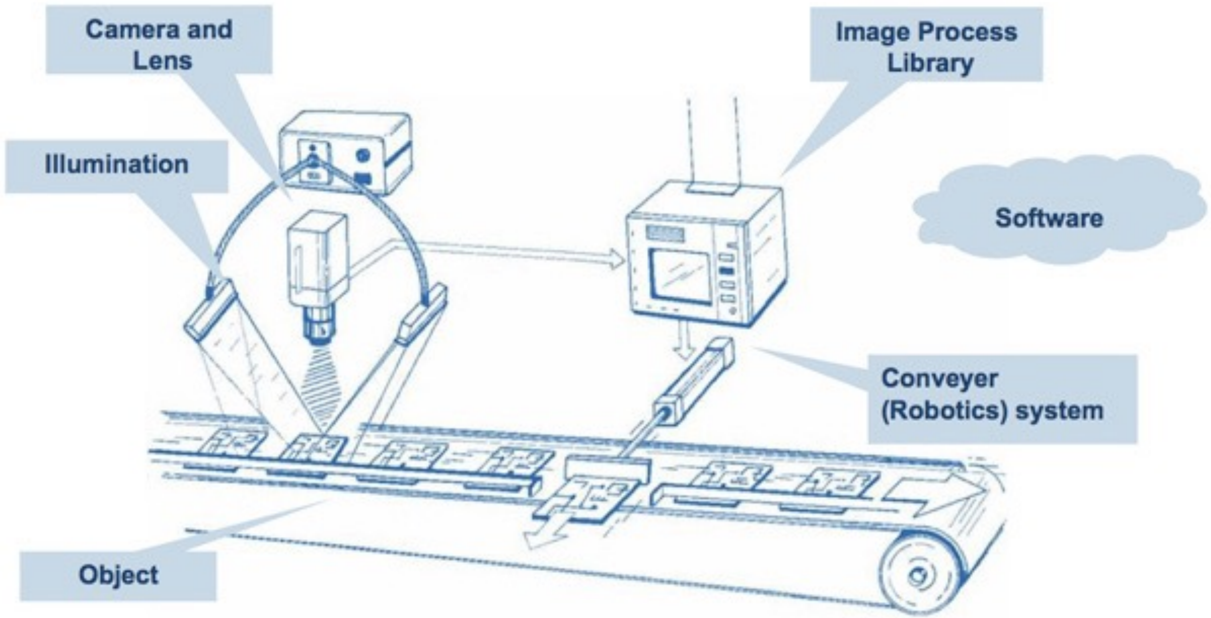
- Used for:
  - Inspection
  - Part Orientation
  - Process Verification
  - Measurement
  - Flaw Detection
  - Part Identification & Tracking
  - Assembly
  - Robotic & machine real-time control





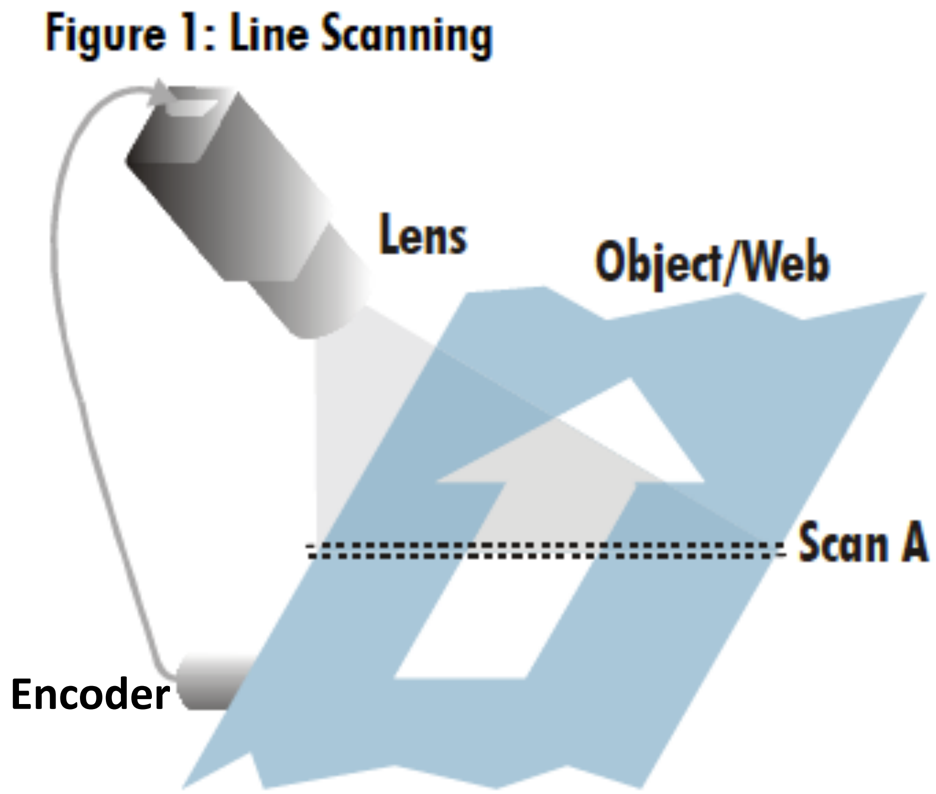
Standard Vision Process

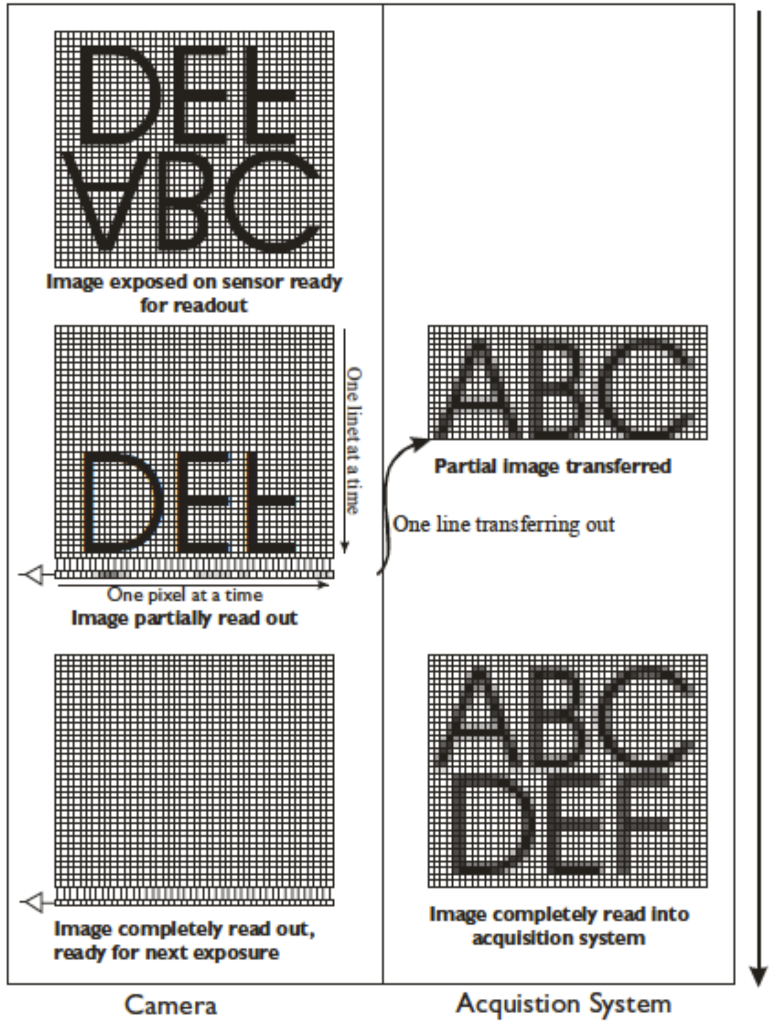
- Position the object or camera so that the camera can view the object or scene
- Capture an image with a camera
- Process the image
- Take action based on the image processing results
- Communicate results to operators and other factory systems



Source:
https://www.digikey.com/~/media/Images/Article%20Library/TechZone%20Articles/2012/January/Versatile%20LEDs%20Drive%20Machine%20Vision%20in%20Automated%20Manufacture/article-2012january-versatile-leds-drive-fig1.jpg

Example: line scanning camera



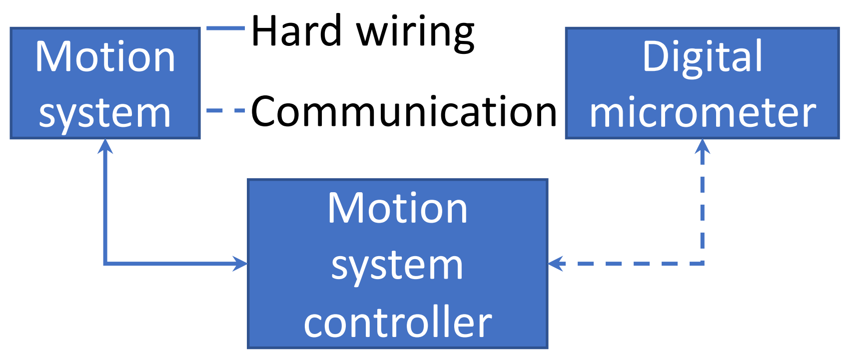


Line scan imagers such as document scanners use a single line of sensor pixels to build up a two-dimensional image

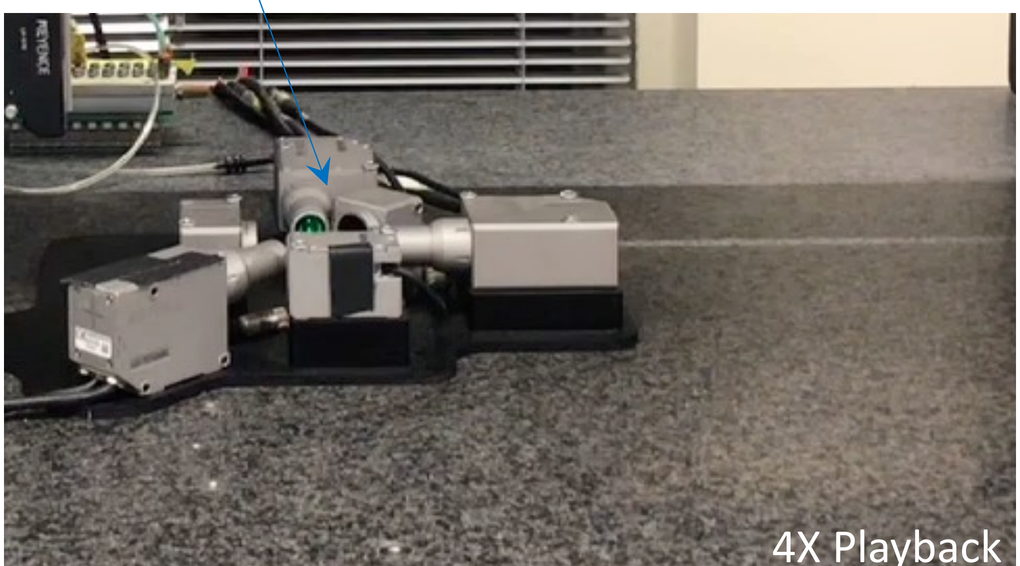
Example: tool registration

Digital micrometer

System diagram



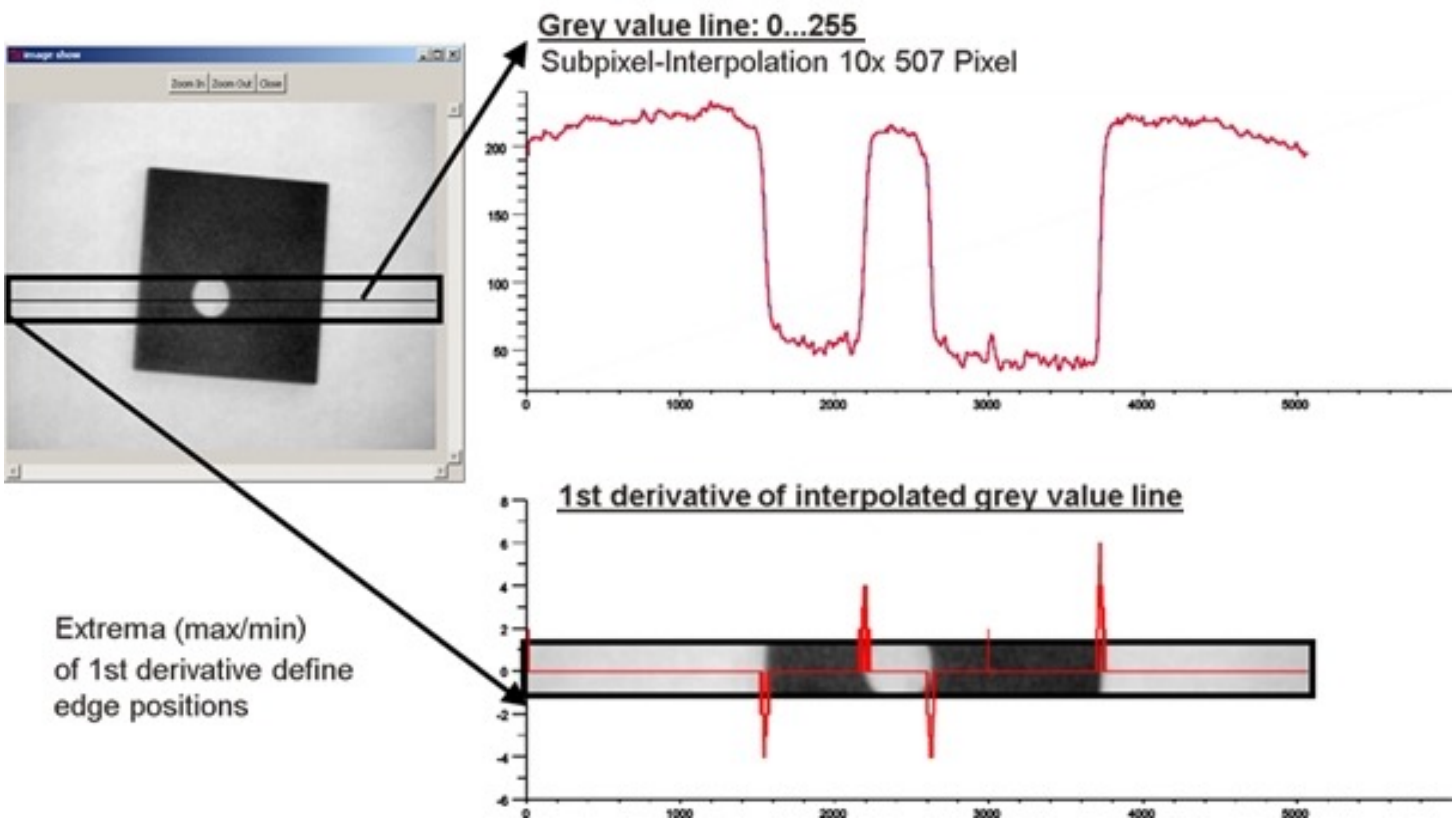
System view



Camera view

How Do Vision Systems Find Objects?

- Edge Detection!
  - If we can find edges, we can also measure size and shape.



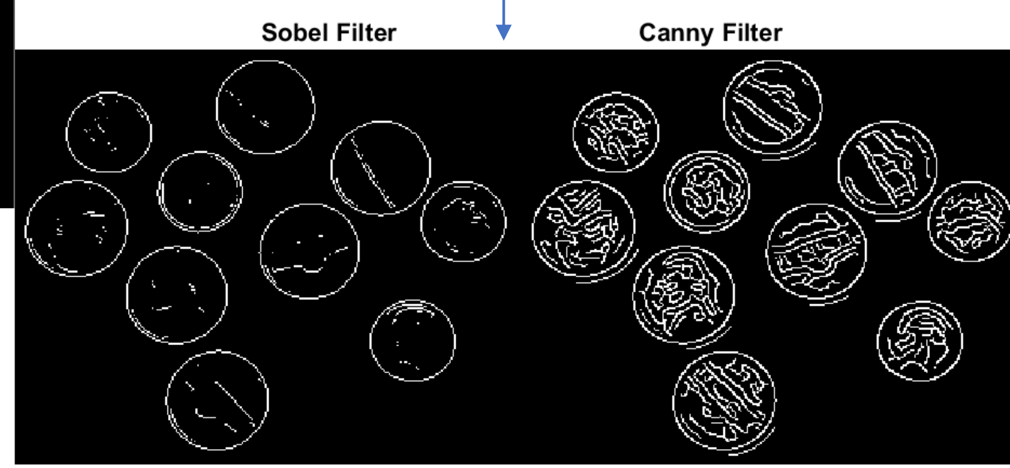
High Speed Vision

- Sorting Pennies

https://youtu.be/L0hXtYKvoLw?t=11s

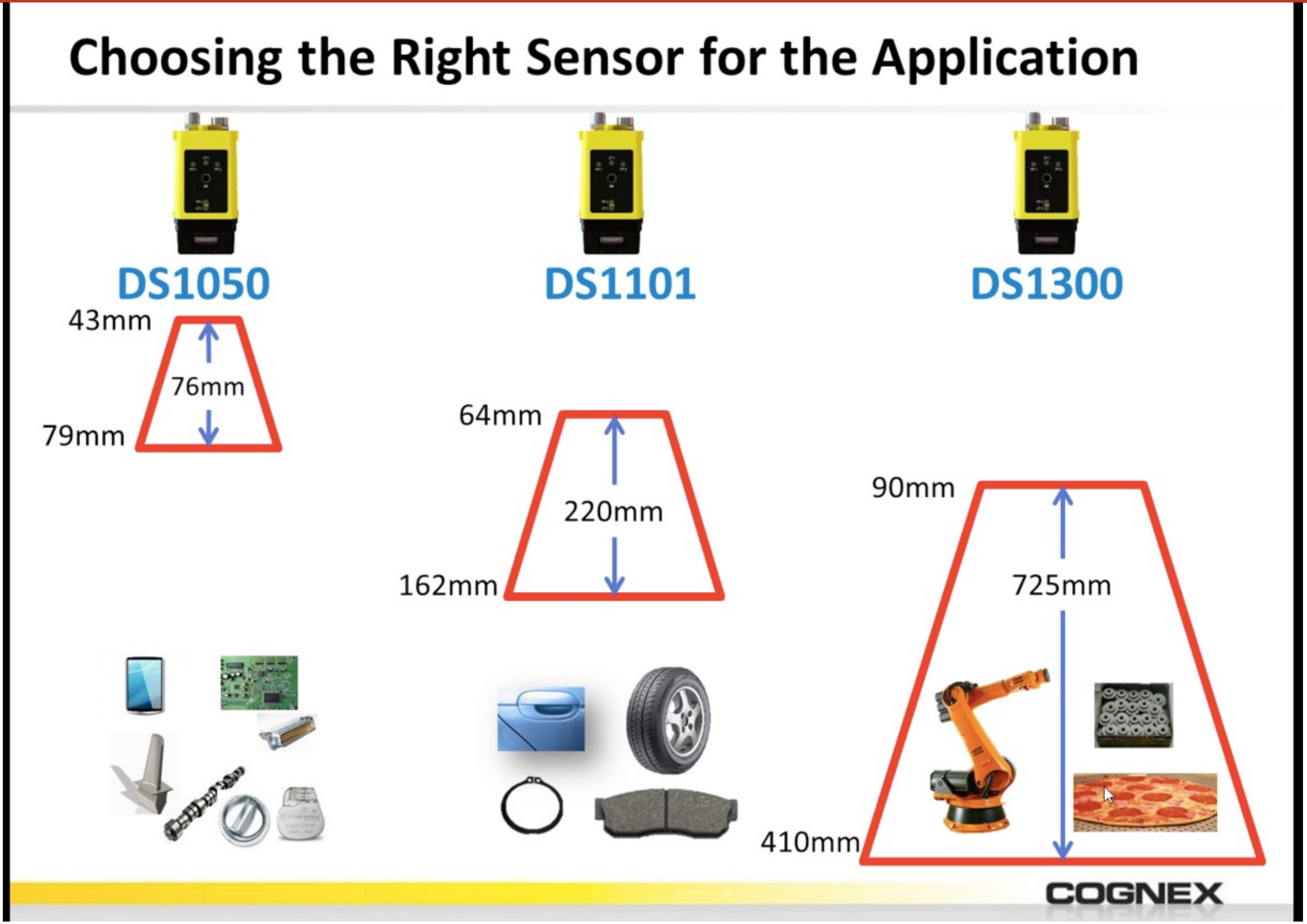
Try this in Matlab!

https://www.mathworks.com/help/images/edge-detection.html#buh9ylp-13



Second Kahoot!

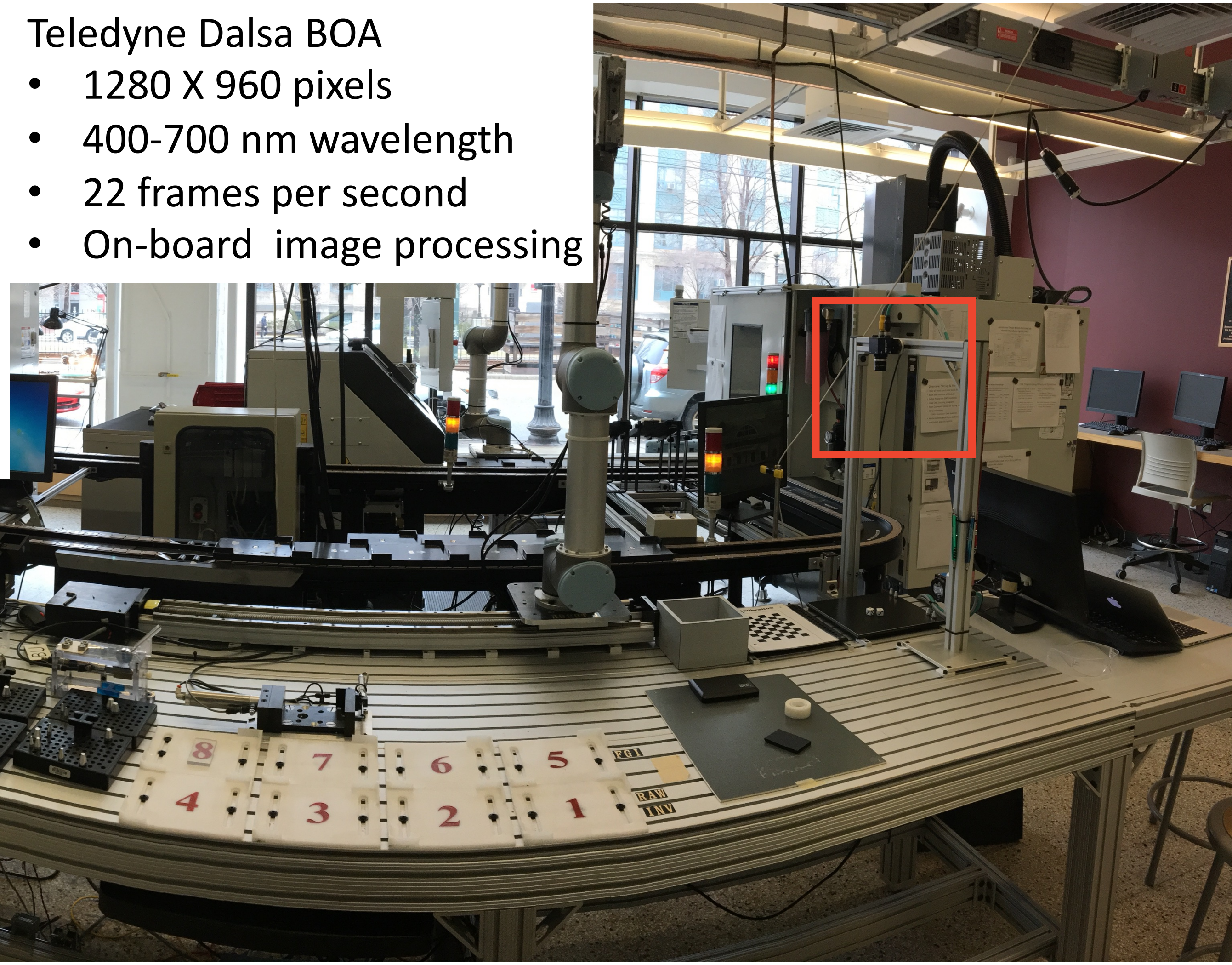
Fixed Lens Focal Depth Ranges



ADML cameras

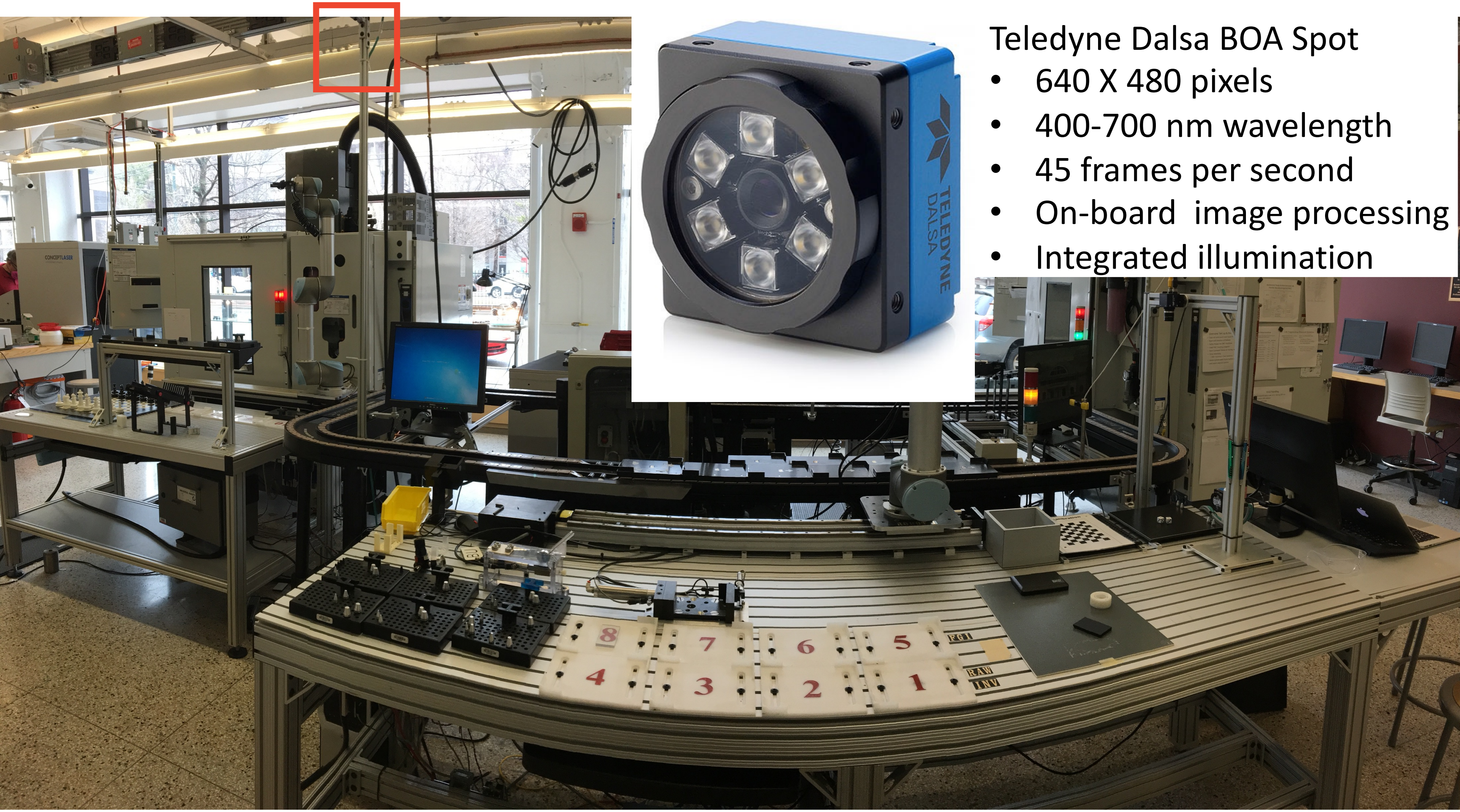
Teledyne Dalsa BOA

- 1280 X 960 pixels
- 400-700 nm wavelength
- 22 frames per second
- On-board image processing



Used for Vision and **Advanced Robotics and Integration Lab**

ADML cameras

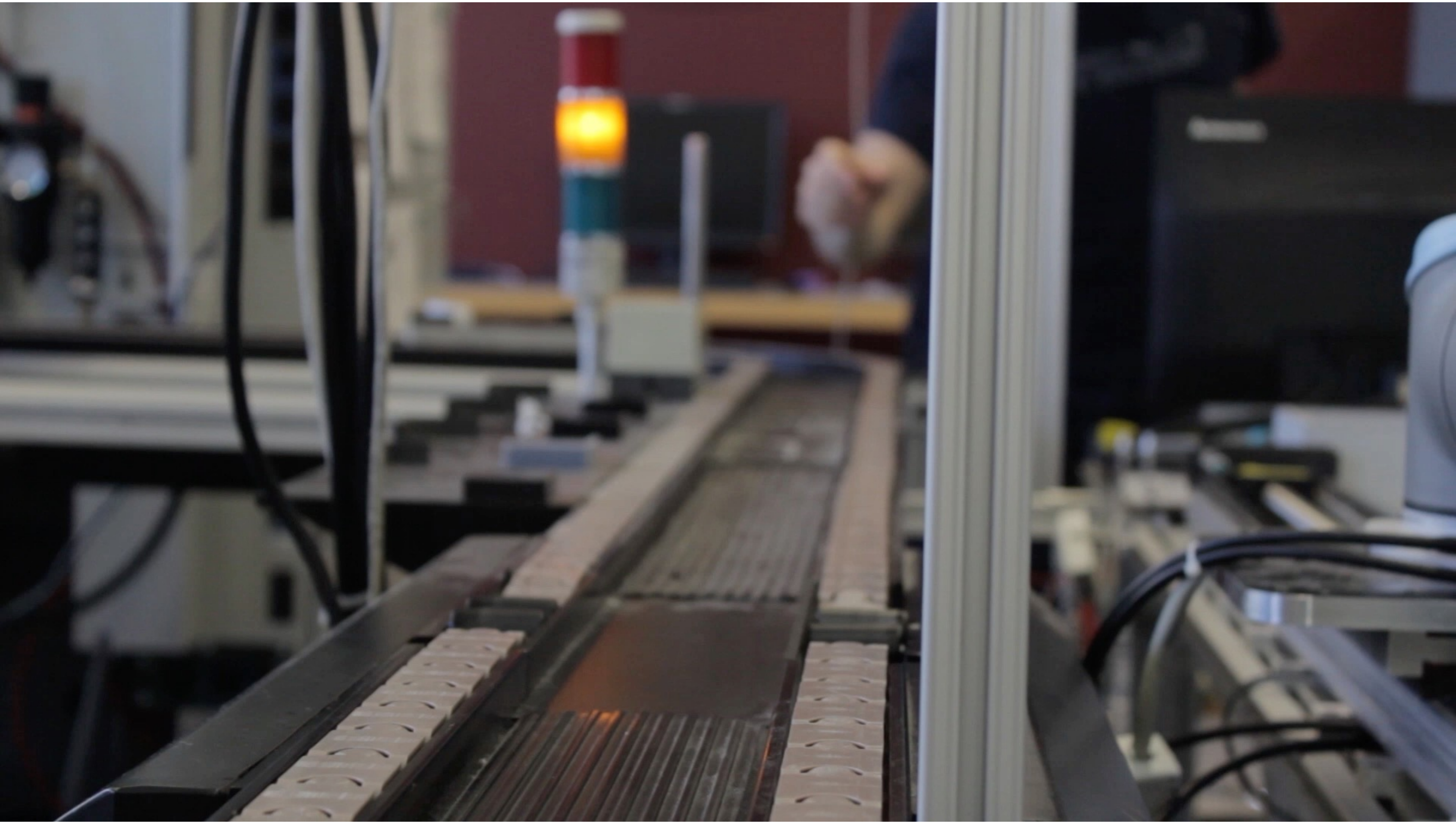


Teledyne Dalsa BOA Spot

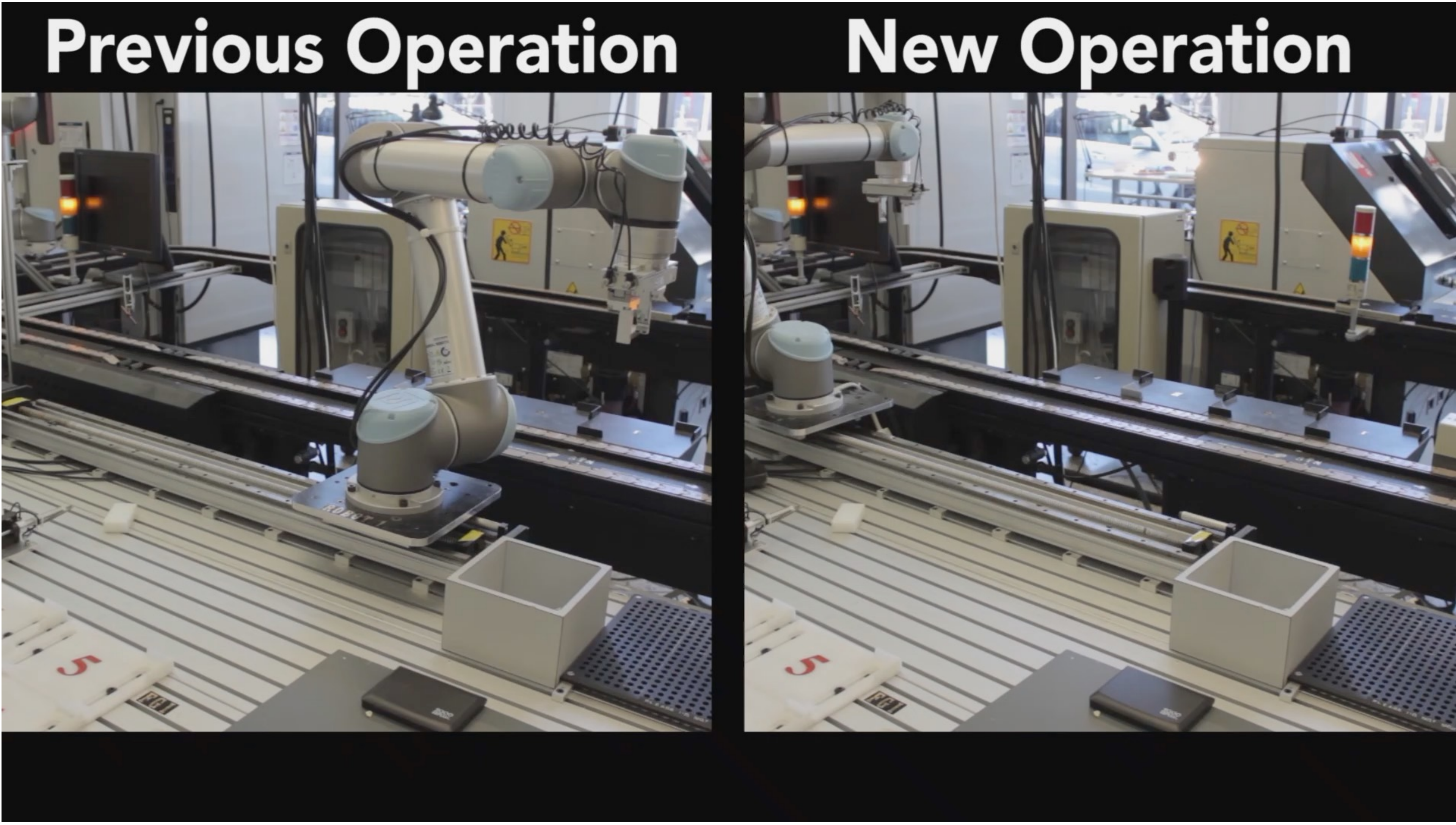
- 640 X 480 pixels
- 400-700 nm wavelength
- 45 frames per second
- On-board image processing
- Integrated illumination

Used for former senior design project – dynamic pick and place (P+P)

Senior design dynamic P+P



Senior design dynamic P+P

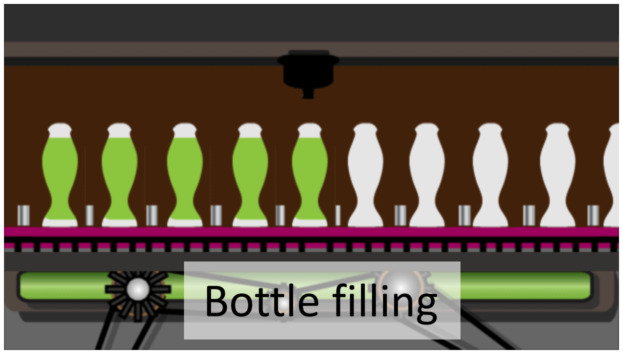


Advanced robotics and integration

- When do robots make sense?
- Examples of advanced robotics in manufacturing
- System integration
  - Definition and evolution
  - ADML system integration and common methods
    - Digital I/O
    - Communication protocols
    - File transfer protocols
  - Examples of integrating systems outside of ADML (time permitting)

When do robots make sense?

Repetitive work

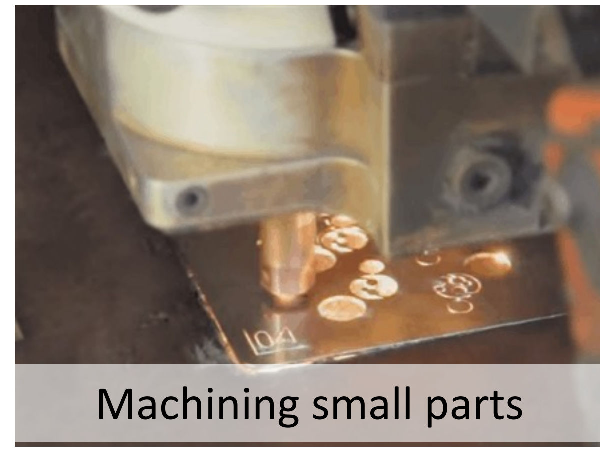


Bottle filling

Dirty work

Casino food recycling

Speed and precision

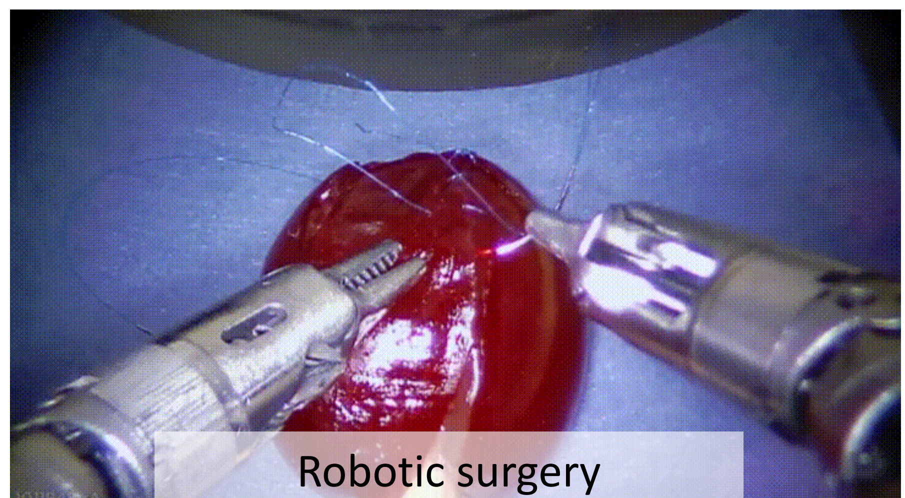


Machining small parts

Dangerous work

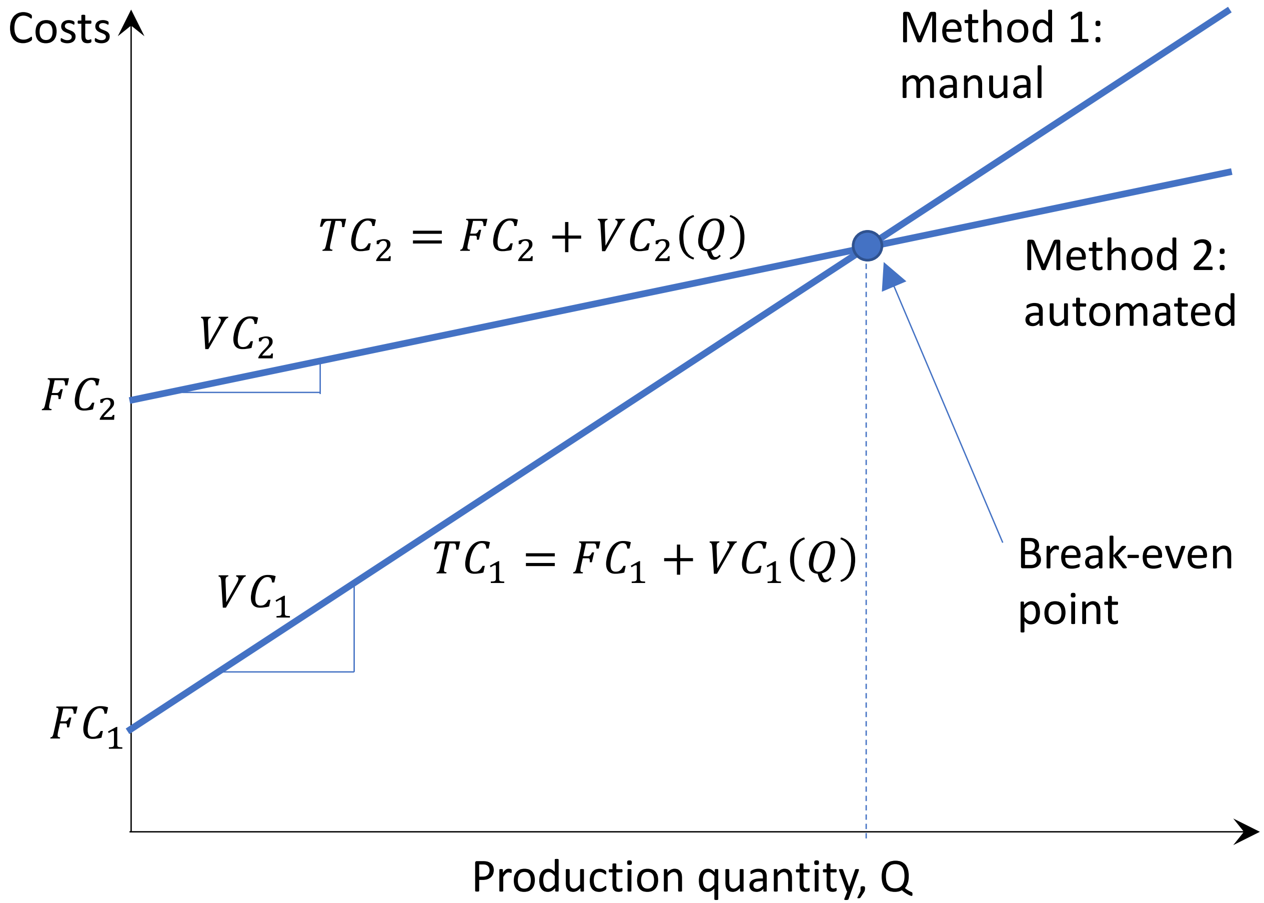
Radioactive materials handling

Work with human to improve process



Robotic surgery

Cost of manual vs. automation



FC – Fixed cost, VC – Variable cost, TC – Total cost

M. P. Groover, Automation, Production Systems, and Computer Integrated Manufacturing, 4th edition

Manufacturing examples

Warehouse robots

Amazon Kiva

Source: https://wonderfulengineering.com/amazons-warehouse-robots/

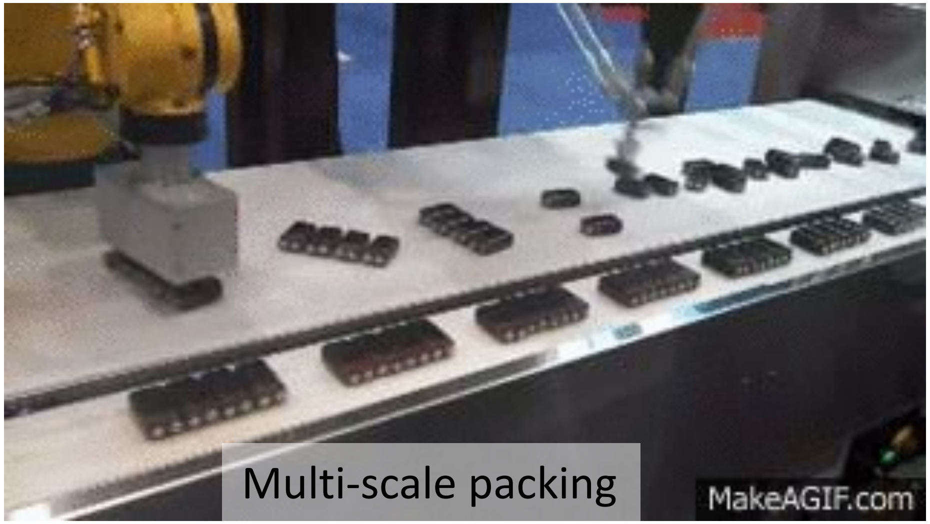
Alibaba: material handling

Pick and place robots

Manufacturing examples

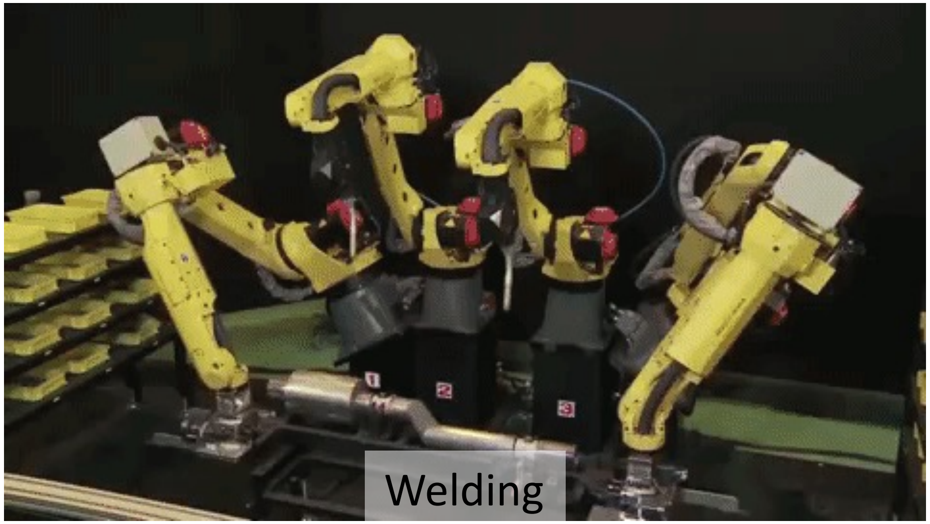
Multiple integrated robots

Delta (assembles small parts) + Articulated (orients sub-assembly)



Source: http://fat.gfycat.com/OrneryBouncyGilamonster.gif

Fanuc R1000



Source: https://media.giphy.com/media/Ojqy3c2NQdQ88/giphy.gif

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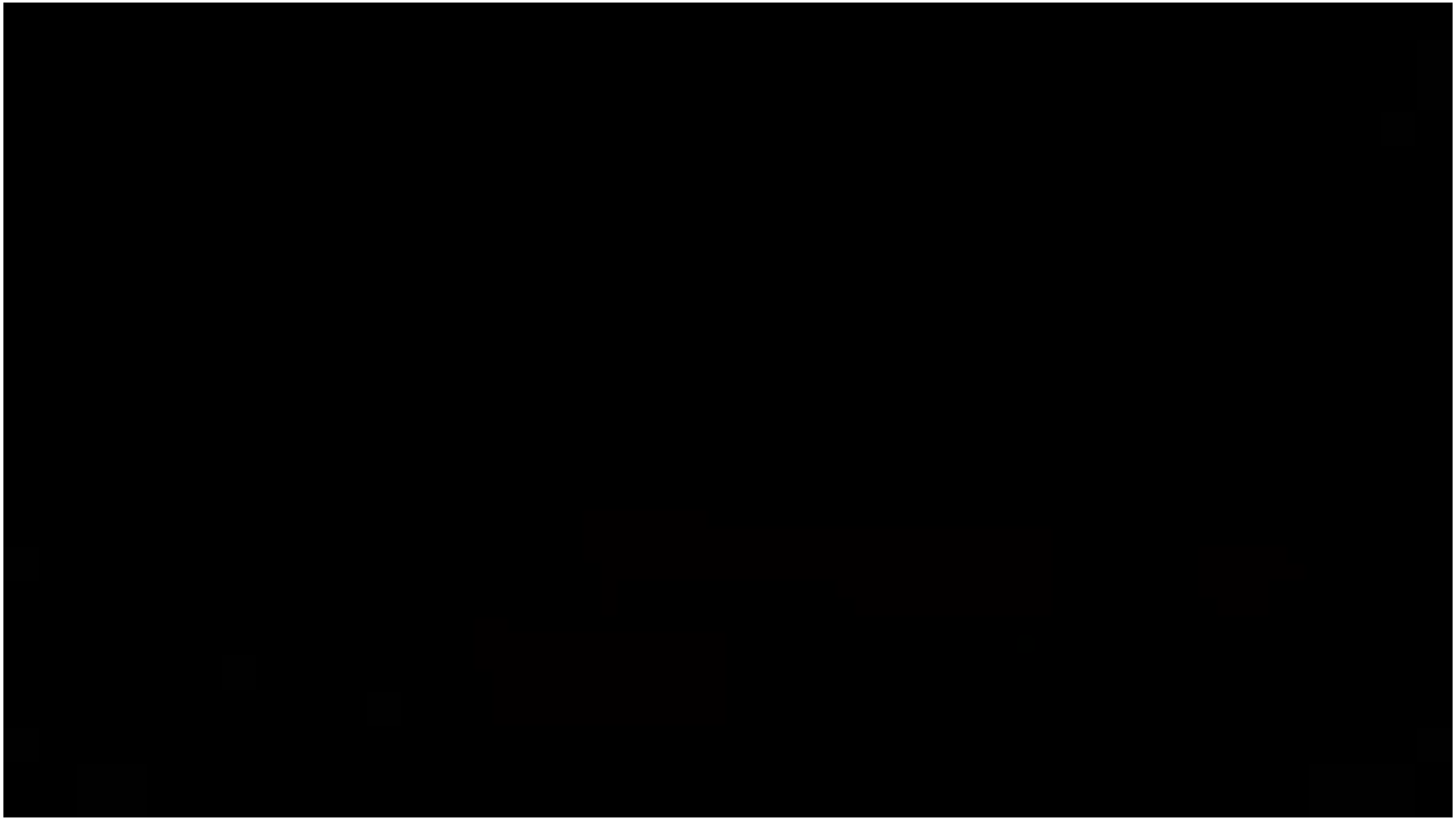
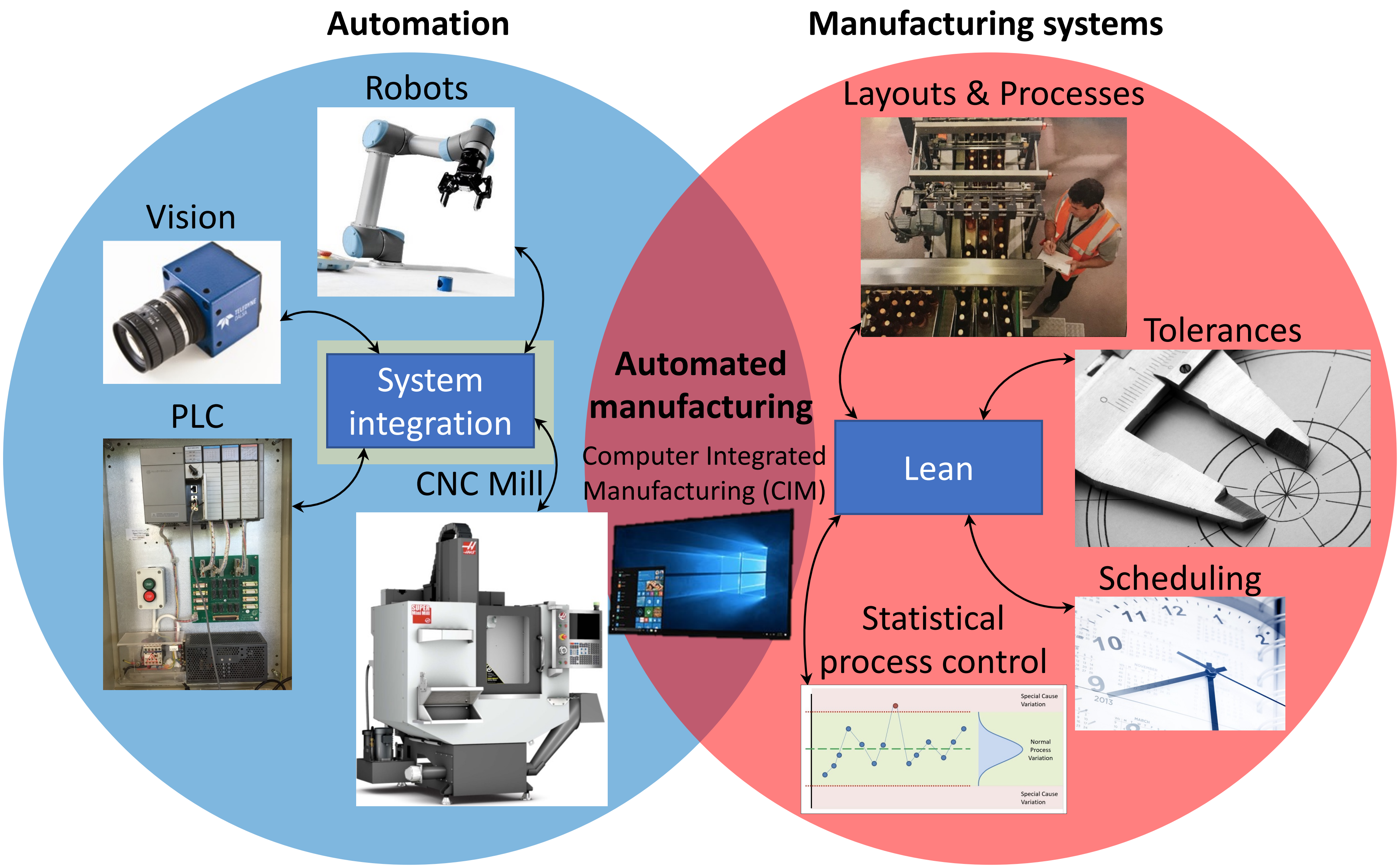
Kia sportage factory



https://www.youtube.com/watch?v=sjAZGUcjrP8

Third Kahoot!

Course overview – system integration



System integration

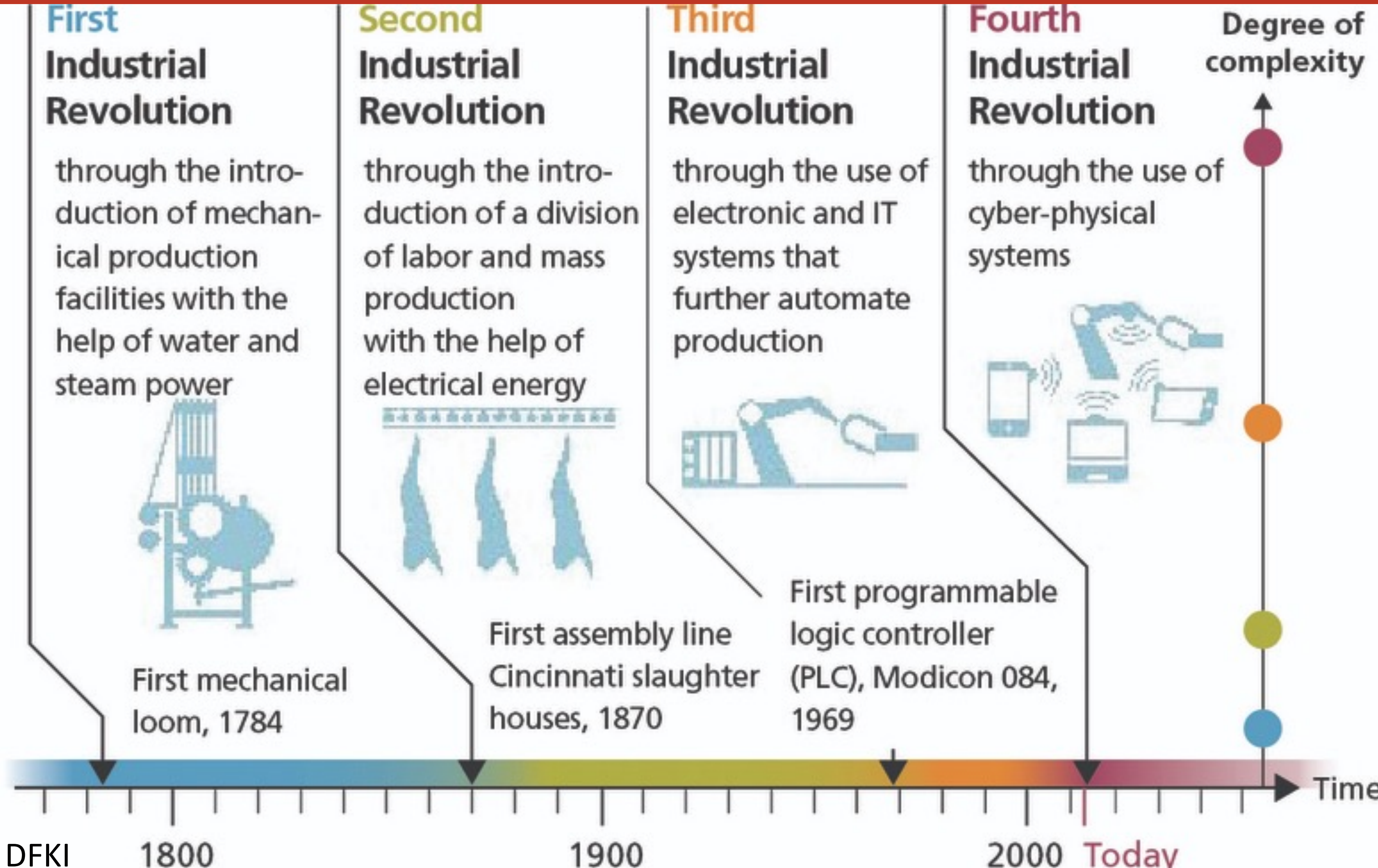
- Definition and evolution
- ADML system integration and common methods
  - Digital I/O
  - Communication protocols
  - File transfer protocols
- Examples of integrating systems outside of ADML (time permitting)

System integration

System integration

"The process of bringing together the component sub-systems into one system (an aggregation of subsystems cooperating so that the system is able to deliver the overarching functionality) and ensuring that the subsystems function together as a system" – H. T. Gilkey. New Air Heating Methods. 1960

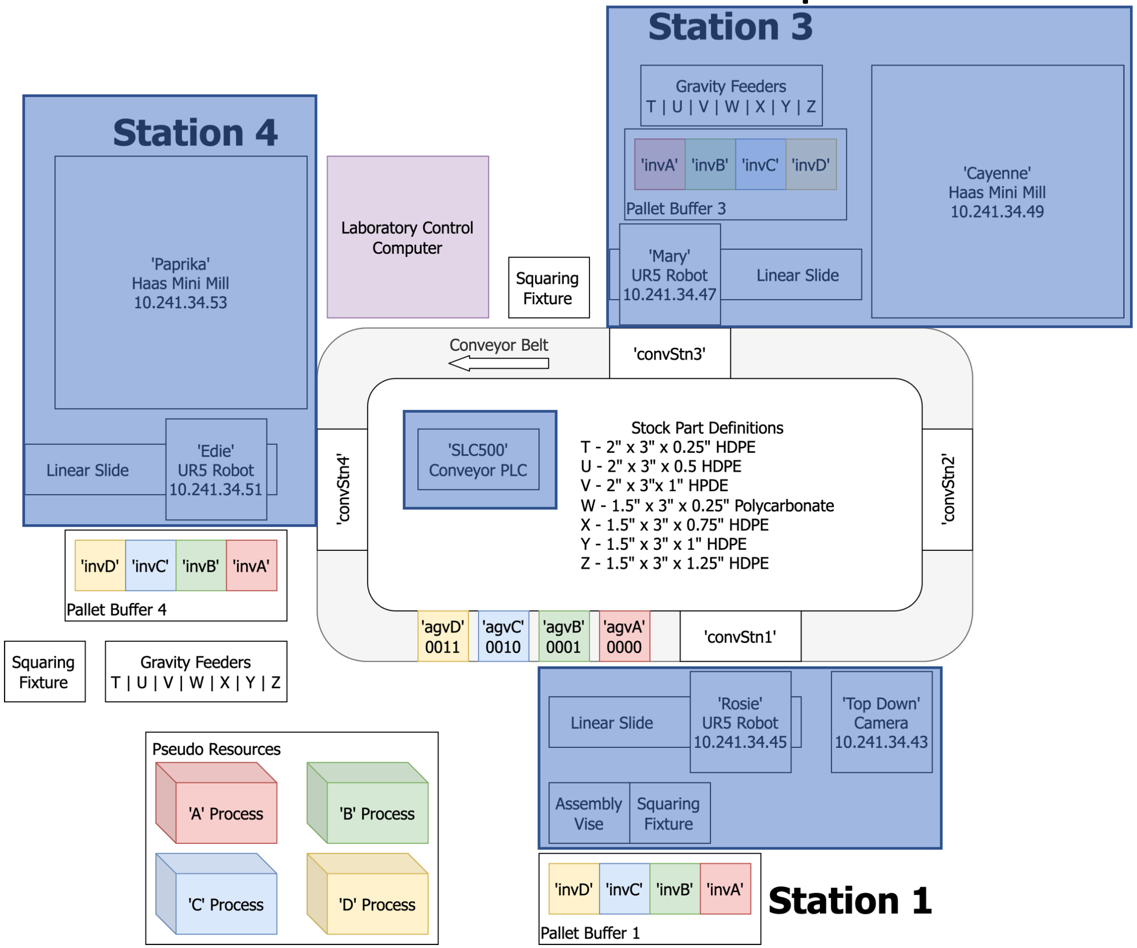
Evolution of system integration in automated manufacturing



DFKI

ADML system integration

How do we connect and coordinate multiple automation systems?

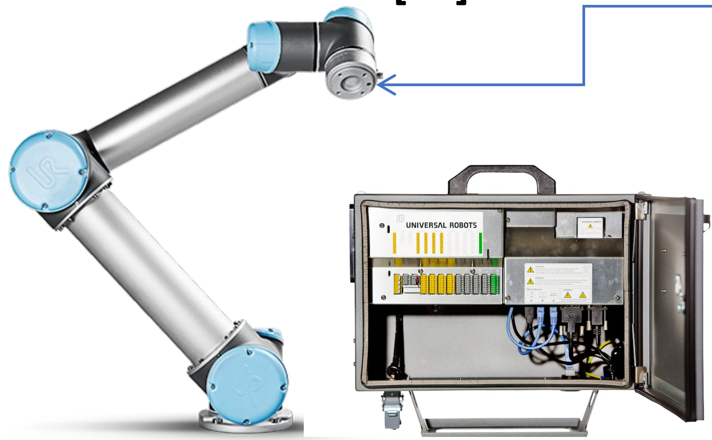


Digital input/output (I/O) **Communication protocols** **File transfer protocols**

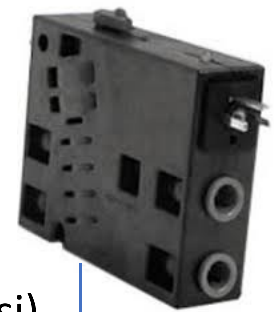
These three are used widely in industry to connect multiple automated sub-systems

Digital input/output (I/O)

UR-5 [x3]



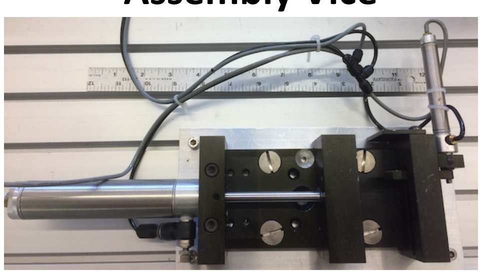
24V DC
(On/Off)



Isonic V4A-0307-BW1 Solenoid Valve

Air (90 psi)

Assembly Vice



Haas MiniMill MM-1 [x2]

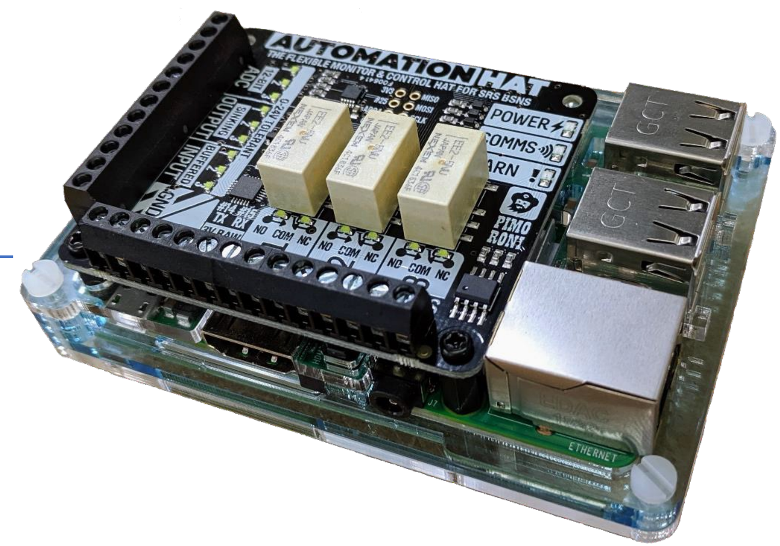
For advanced robotics lab

Robot controller independently outputs 24V DC to solenoids that control pneumatic **vise jaws** in each mill, assembly vice, and the individual robot grippers

Digital input/output (I/O)

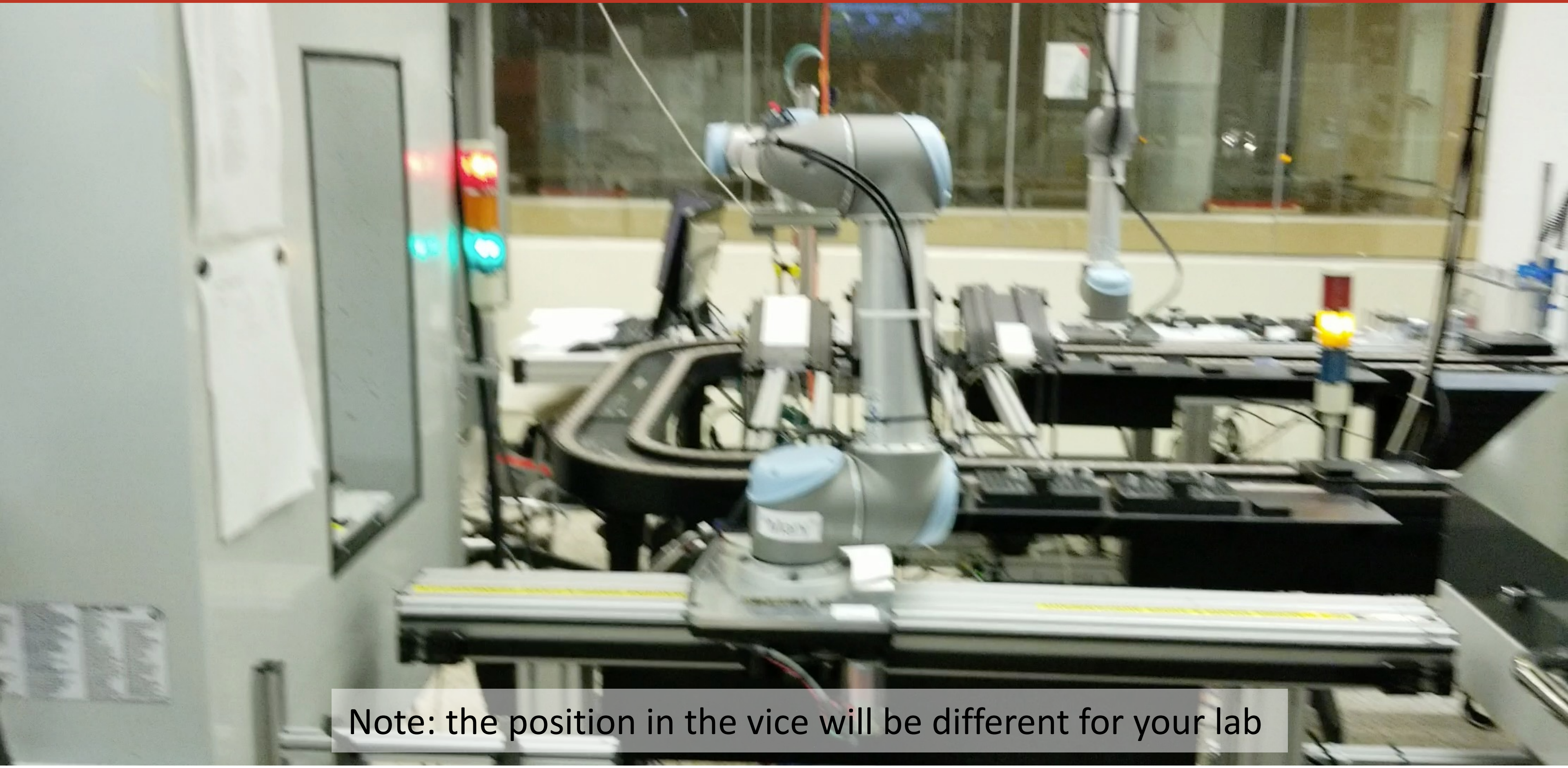
Haas MiniMill MM-1 [x2]

VersaBuilt Robotics Robot2CNC Basic [x2]



The Robot2CNC is hard-wired to cycle start button of mills and will turn cycle start to start a CNC program once it is loaded from the CNC's local memory. This is also used for the advanced robotics lab.

Machine tending

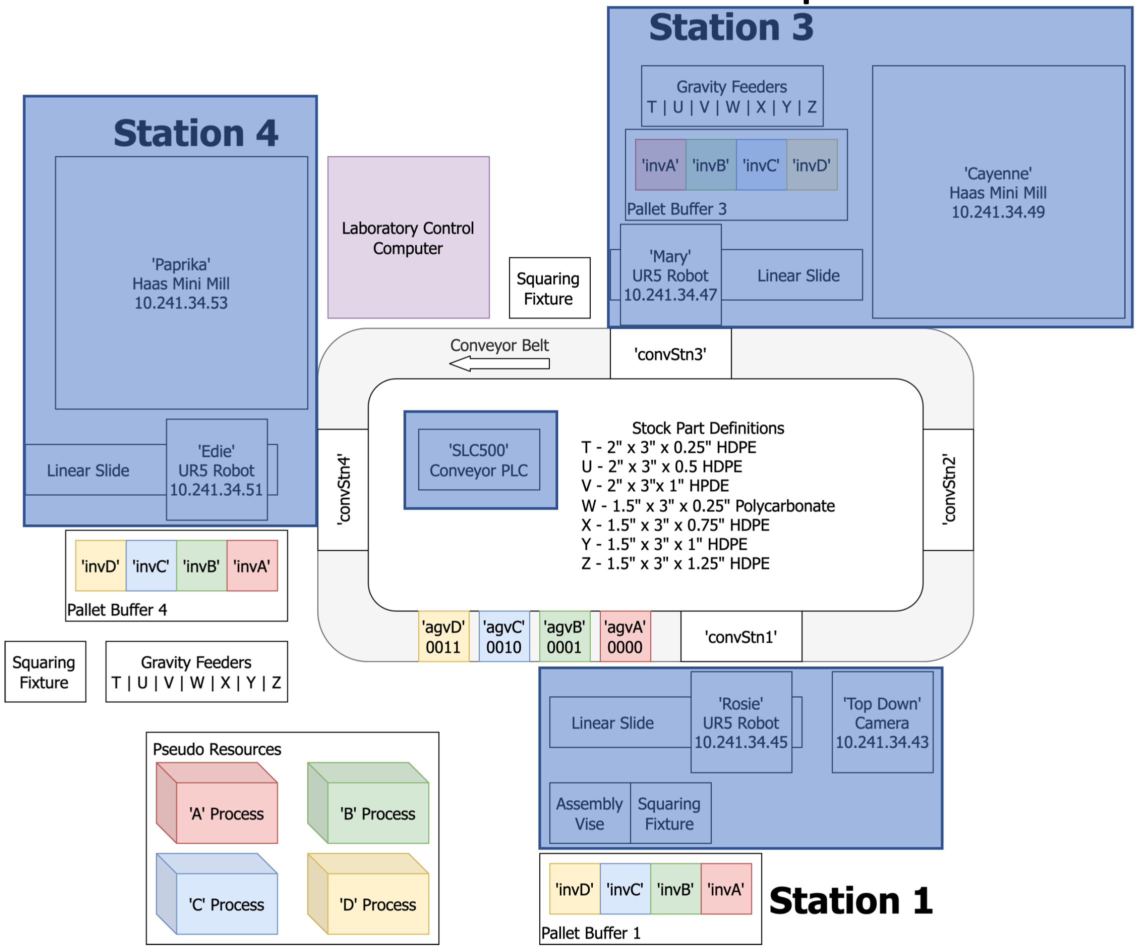


Note: the position in the vice will be different for your lab

- A lot of information is passed between systems
- Requires more information than digital IO ('on' or 'off')
- E.g., telling an automated sub-system to perform a task

ADML system integration

How do we connect and coordinate multiple automation systems?

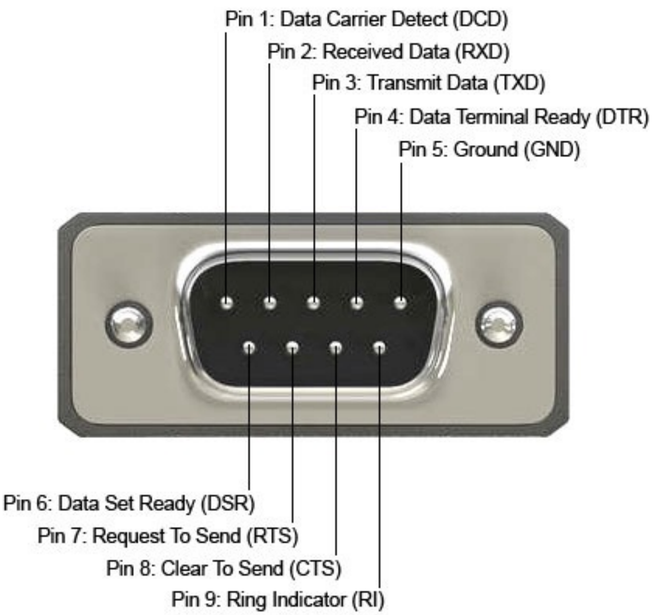


Digital input/output (I/O) **Communication protocols** **File transfer protocols**

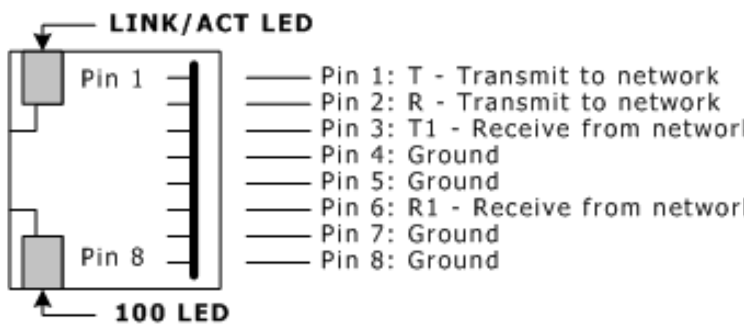
These three are used widely in industry to connect multiple automated sub-systems

Communication connection types

RS – 232



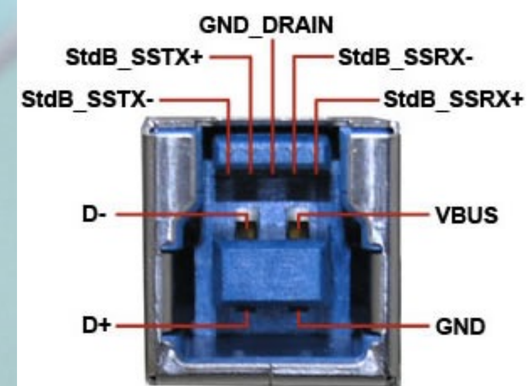
Ethernet



Pins 4, 5, 7, and 8 are grounded through a spark gap for 100Base-T Ethernet connections

USB 3.0

SuperSpeed standard B plug pinout



1	VBUS	Red
2	D-	White
3	D+	Green
4	GND	Black
5	StdA_SSTX-	Blue
6	StdA_SSTX+	Yellow
7	GND_DRAIN	GROUND
8	StdA_SSRX-	Purple
9	StdA_SSRX+	Orange
Shell	Shield	Connector Shell

usconverters.com
nmscommunications.com
pinout.net

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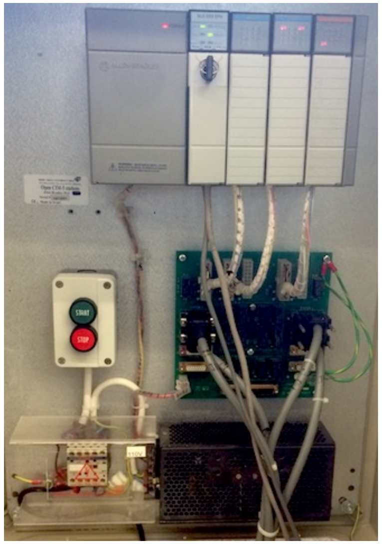
PLC/Conveyor

Lenovo M93P Tower

Serial (RS232 converted to Ethernet)

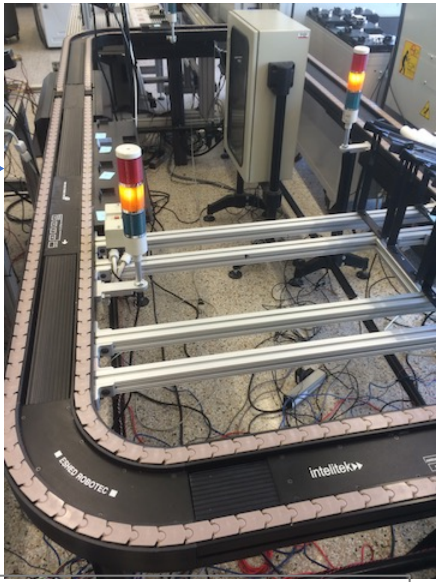
Moxa Nport 5110a

Allen Bradley PLC



Digital I/O [x4]
4 stations
Each station has 5 hall effect sensors and 1 pneumatic solenoid valve

ESCHED/Intelitek conveyor (magnetic AGV readers and solenoid stops)



Rockwell Automation RSLogix 500 &
NI Labview
BU CIM software

The PLC:

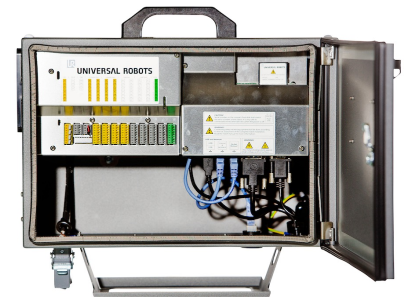
- controls the states of the solenoids at each of the four 'Stations'
- reads the magnetic signature unique to each of the 12 automated guided vehicles (AGVs) that transport pallets around the track
- Serial connections used to download PLC programs (ladder logic) to the PLC, send instructions to the PLC, and read the output (state) into the CIM software

Ethernet – TCP/IP

Netgear ProSafe GS116E

All connections Ethernet TCP/IP

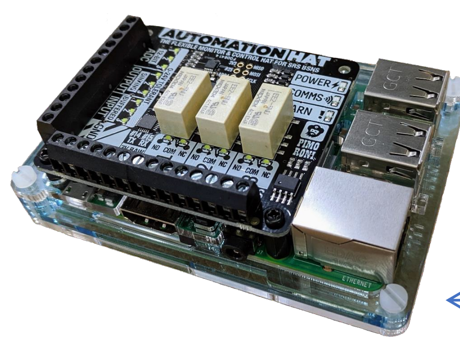
UR-5 Controller [x3]



Lenovo M93P Tower (CIM Computer)

Moxa Nport 5110a [x4] (To Linear Slide Motor Controllers, and Conveyor PLC)

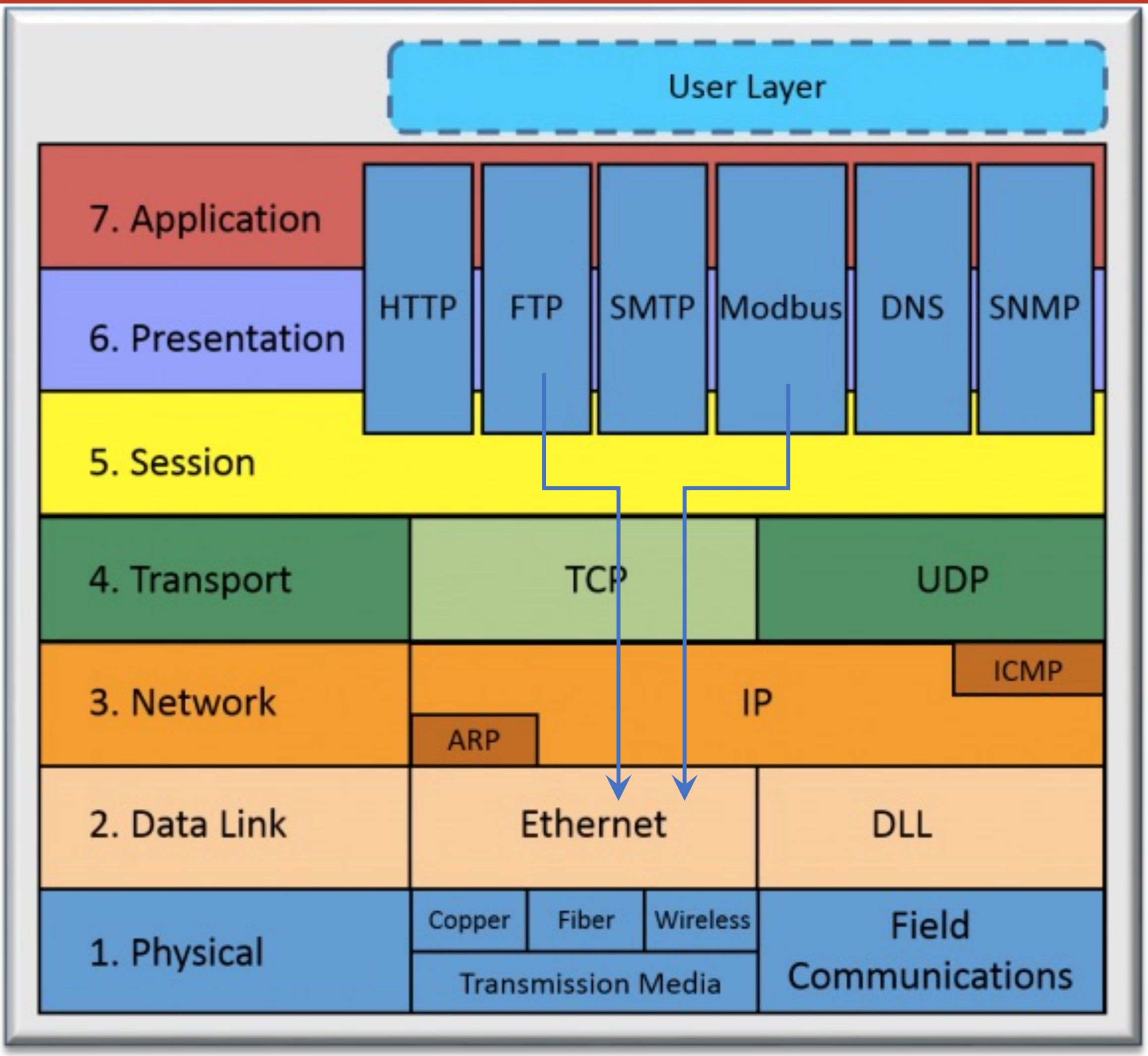
VersaBuilt Robotics Robot2CNC Basic [x2]



Haas MiniMill MM-1 [x2]

RS232/USB3.0 Communication

Communication protocol types



OSI model builds a protocol in layers

https://library.automationdirect.com/plc-communications-coming-of-age/

Modbus: serial communication protocol

TCP: Transmission control protocol

IP: Internet protocol

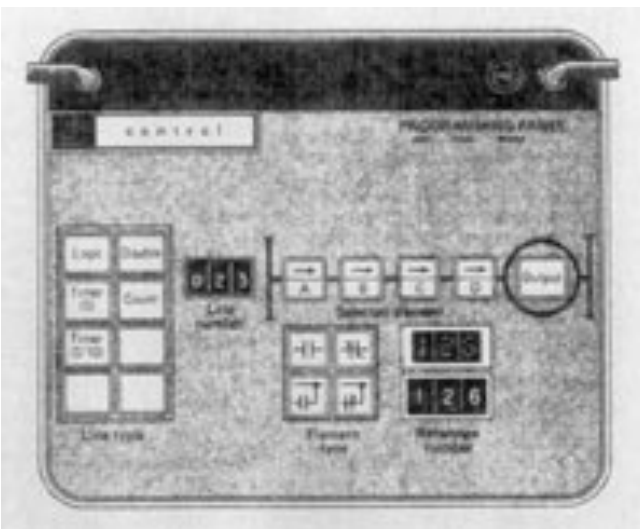
FTP: file transfer protocol, standard network protocol

Why is it called MODBUS?

First introduced by MODICON (now part of Schneider Electric) in 1979

- Openly published
- Royalty-free

First PLC: MOdular DIgital CONtroller (MODICON) - 1970



https://www.redviking.com/

Schneider Electric

https://en.wikipedia.org/wiki/Schneider_Electric

https://en.wikipedia.org/wiki/Modbus

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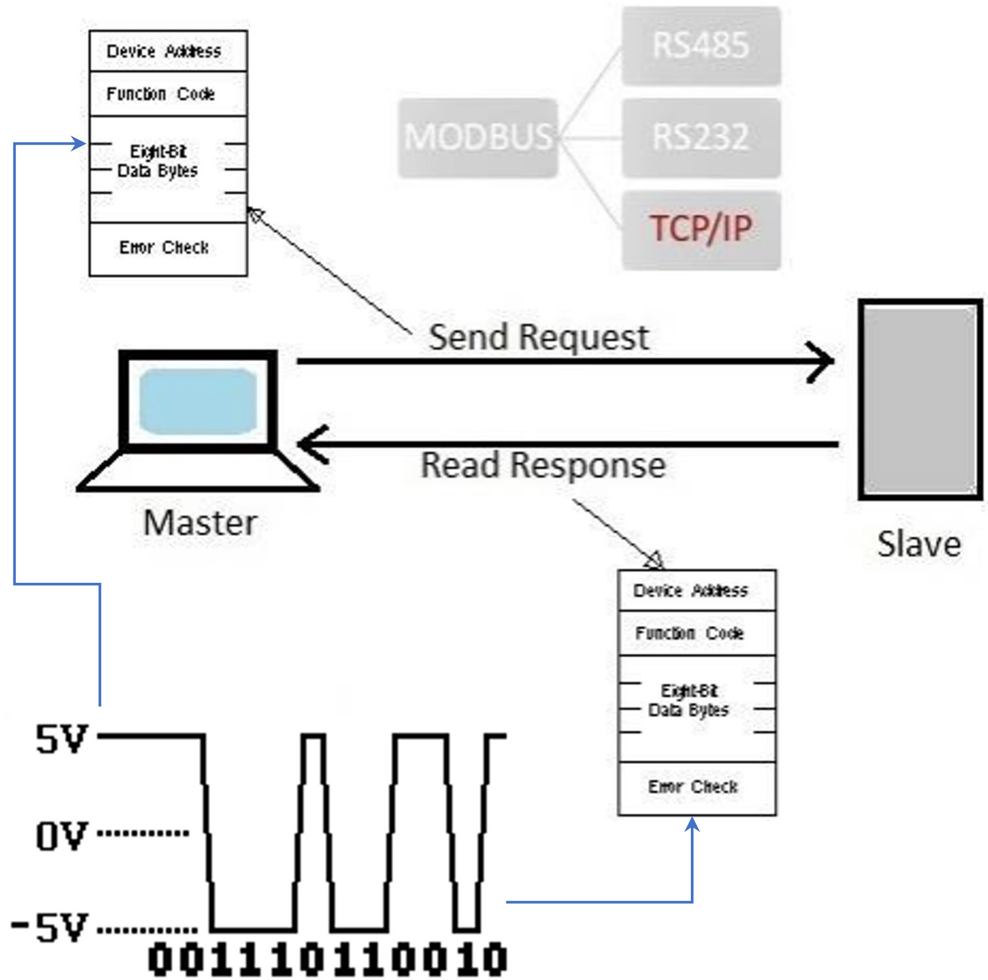
How does MODBUS work?

- Data is sent between machines as series of ones and zeroes called <u>bits</u>.
- Each bit is sent as a voltage pulse. Zeros are sent as positive voltages and a ones as negative.
- The **bits** are sent very quickly.
  - Typical transmission speed is 9600 baud or Hz (bits per second)
  - Common speeds: 1200, 2400, 4800, 9600, 19200, 38400, 57600 and 115200... bits per second



Source: https://www.rfwireless-world.com/Tutorials/Modbus-Protocol-tutorial.html
More info on Modbus: https://www.schneider-electric.com/en/faqs/FA168406/

How can we make sense of bits?

- Long strings of ones and zeros are difficult to read, so the bits are combined and shown in hexadecimal.
- Each block of 4 bits can be represented by one of the sixteen (hexadecimal) characters from 0 to F:

```
0000 = 0  0100 = 4  1000 = 8  1100 = C
0001 = 1  0101 = 5  1001 = 9  1101 = D
0010 = 2  0110 = 6  1010 = A  1110 = E
0011 = 3  0111 = 7  1011 = B  1111 = F
```

- Each block of 8 bits (called a byte) is represented by one of the 256 character pairs from 00 to FF
- http://www.asciitohex.com - Convert between ascii, hex, etc.

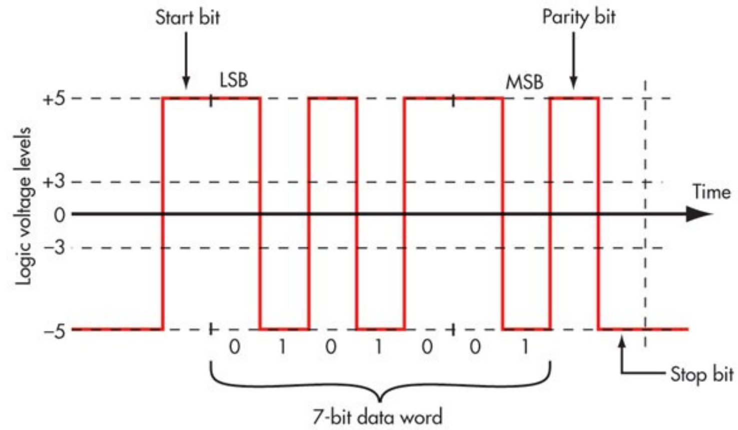
ASCII (American Standard Code for Information Interchange)

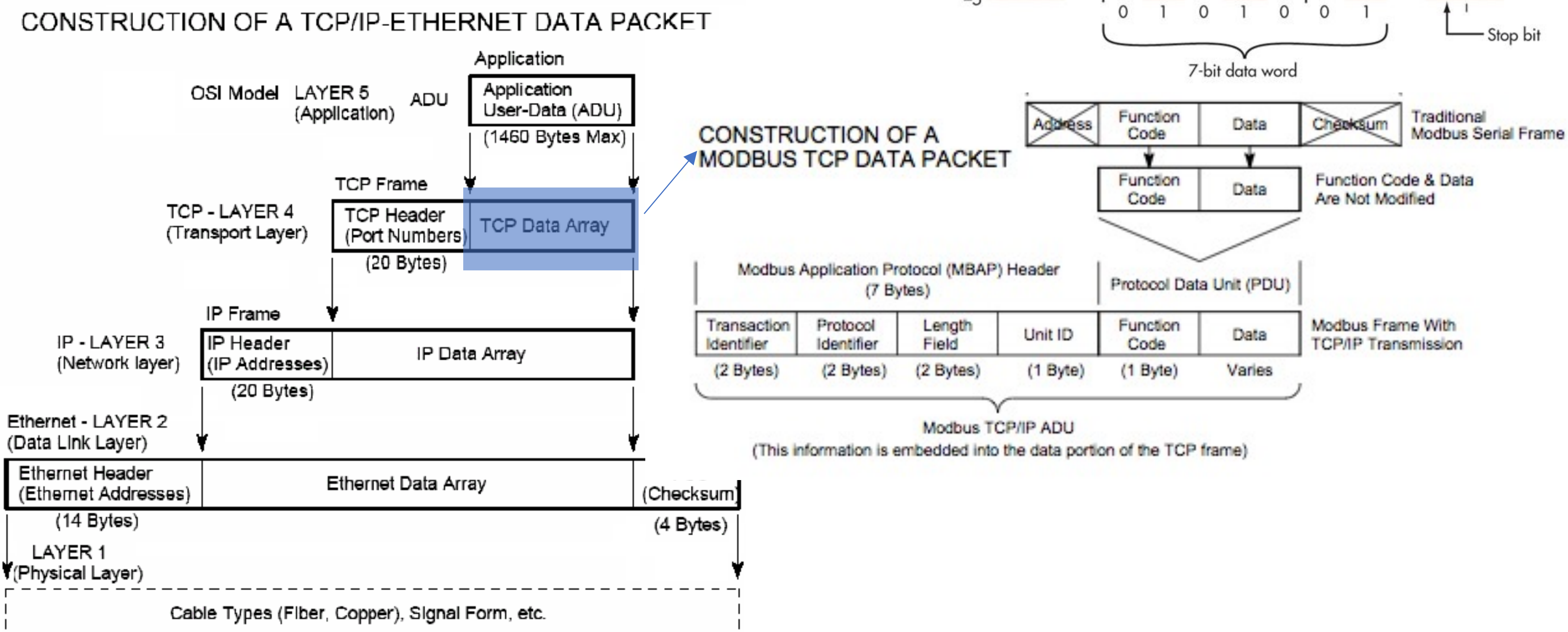
- Every 8-bit byte can be represented by one of 256 ASCII characters, including the common keyboard characters
- For example, some of the values for ASCII characters are...

decimal (base10)	binary (base2)	Hex (base16)	ASCII (base256)
0	0000 0000	0	null
1	0000 0001	1	"
35	0010 0011	23	$
48	0011 0000	30	0
49	0011 0001	31	1
57	0011 1001	39	9
65	0100 0001	41	A
255	1111 1111	FF	ÿ

- So, by using the right encoding, we can send numerical and text data simply by using strings of zeroes and ones
  - Can find this whole list on an ASCII table (http://www.asciitable.com)

Modbus/TCP Data Structure





Data Storage in Modbus

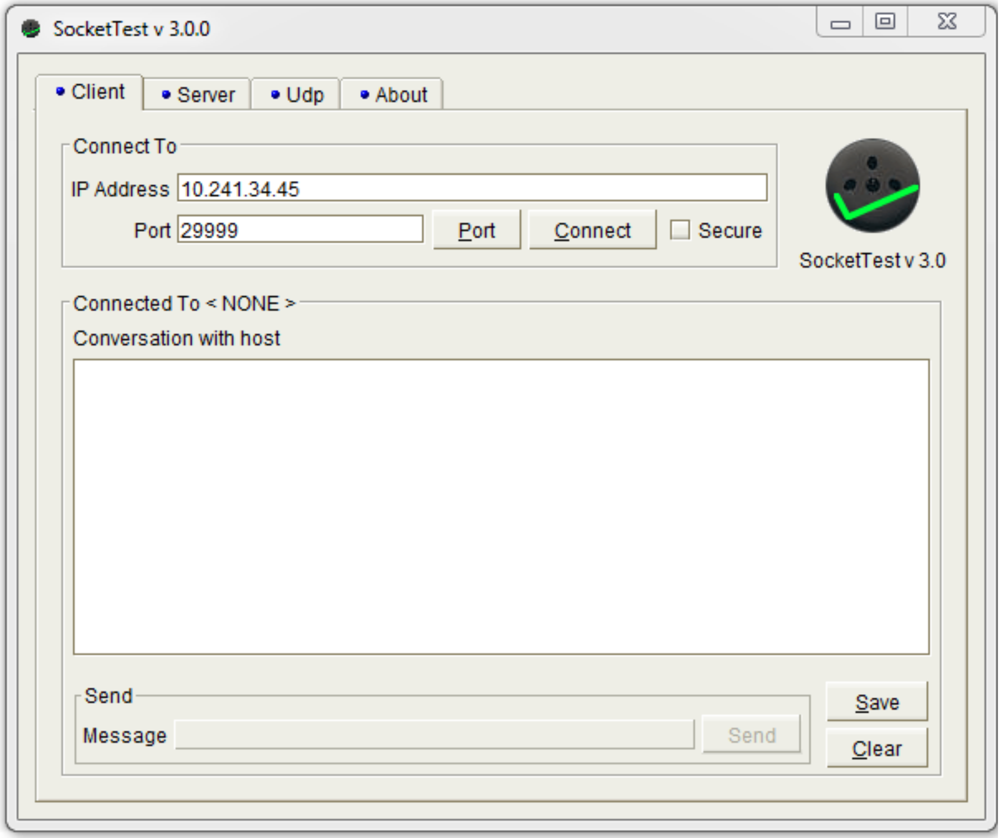
- Stored on the Slave (Server)

Table 1: Modbus Data Types			
Name	**Type**	**Access**	**Visual**
Discrete Input	single bit	read-only	
Discrete Output (Coils)	single bit	read-write	
Input Registers	16-bit word	read-only	
Holding Registers (Registers)	16-bit word	read-write	

- In lab, we use Holding Registers:
  - Robot will be the slave/server (will store the data)
  - Robot and Camera will both read/write from/to the holding registers
- More info:
  - http://www.simplymodbus.ca/faq.htm
  - http://jamod.sourceforge.net/kbase/protocol.html

Modbus TCP/IP between CIM computer and robot

Commanding the robot through TCP/IP



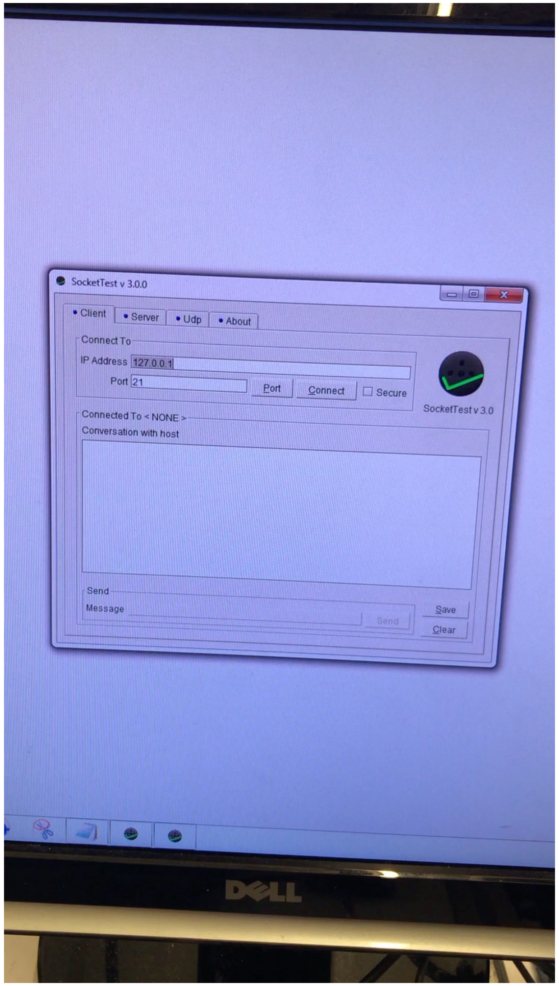
Rosie's Dashboard Server Credentials

IP Address	Port Number	Port Type
10.241.34.45	29999	Load and play files located on robot drive
10.241.34.45	30001	Single line commands (e.g., movej) at 10 Hz
10.241.34.45	30002	100 Hz
10.241.34.45	30003	500 Hz

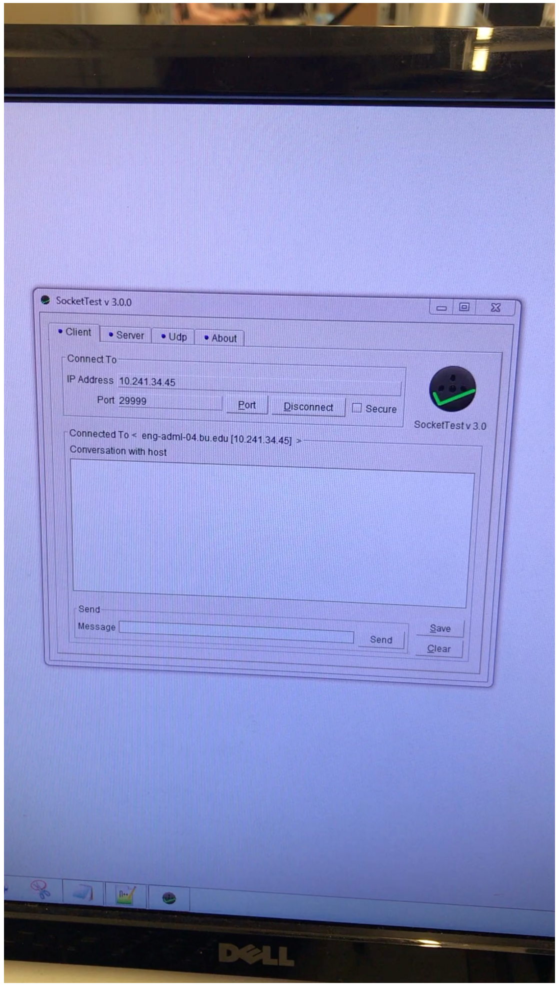
Modbus TCP/IP between CIM computer and robot

Port 29999: Loading and playing files that are on the robot's hard drive (e.g., public folder)

Autohomes_Phome

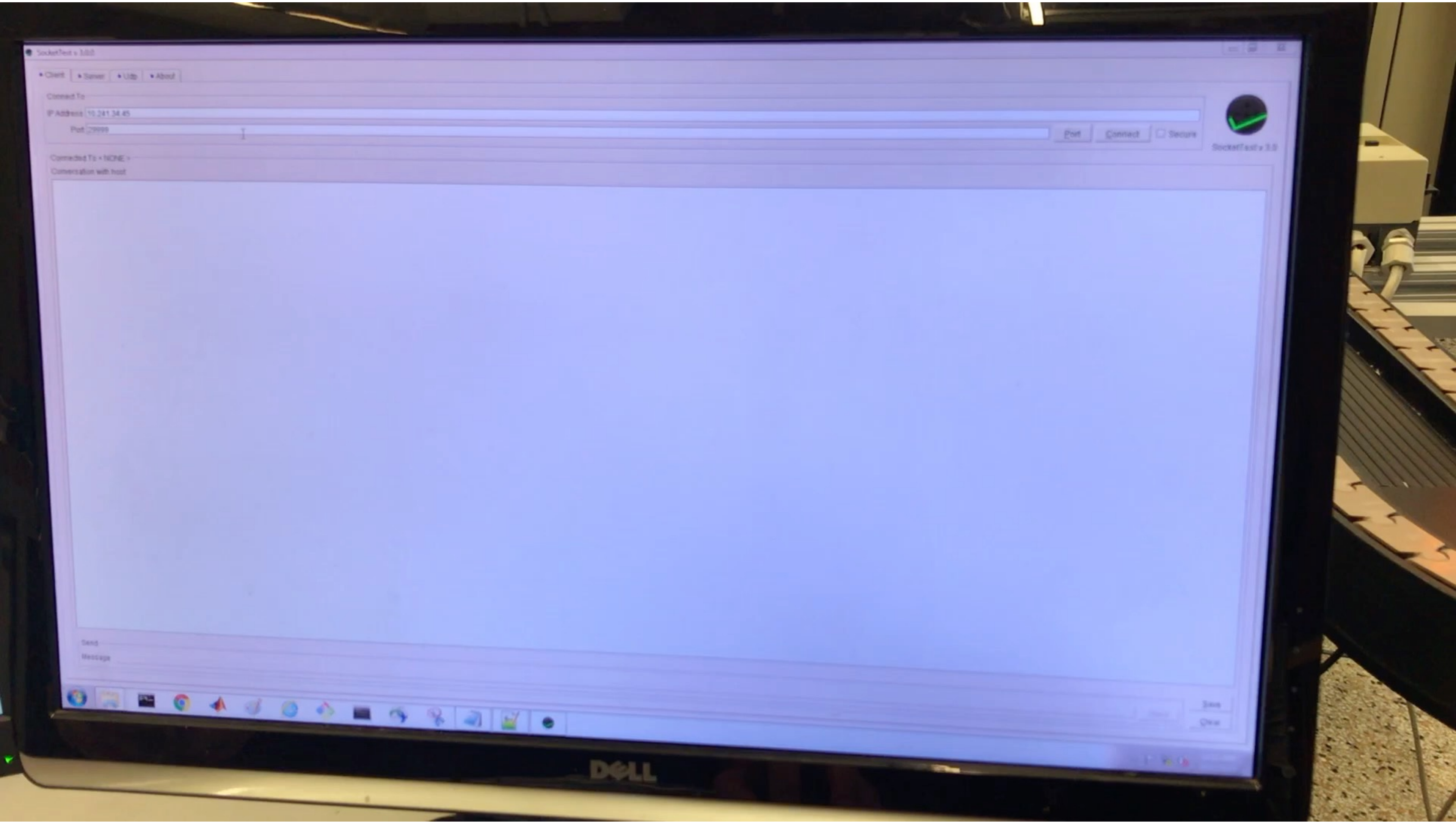


Phome_Homes



Modbus TCP/IP between CIM computer and robot

Port 30001: Direct movej commands – Autohomes_Phome

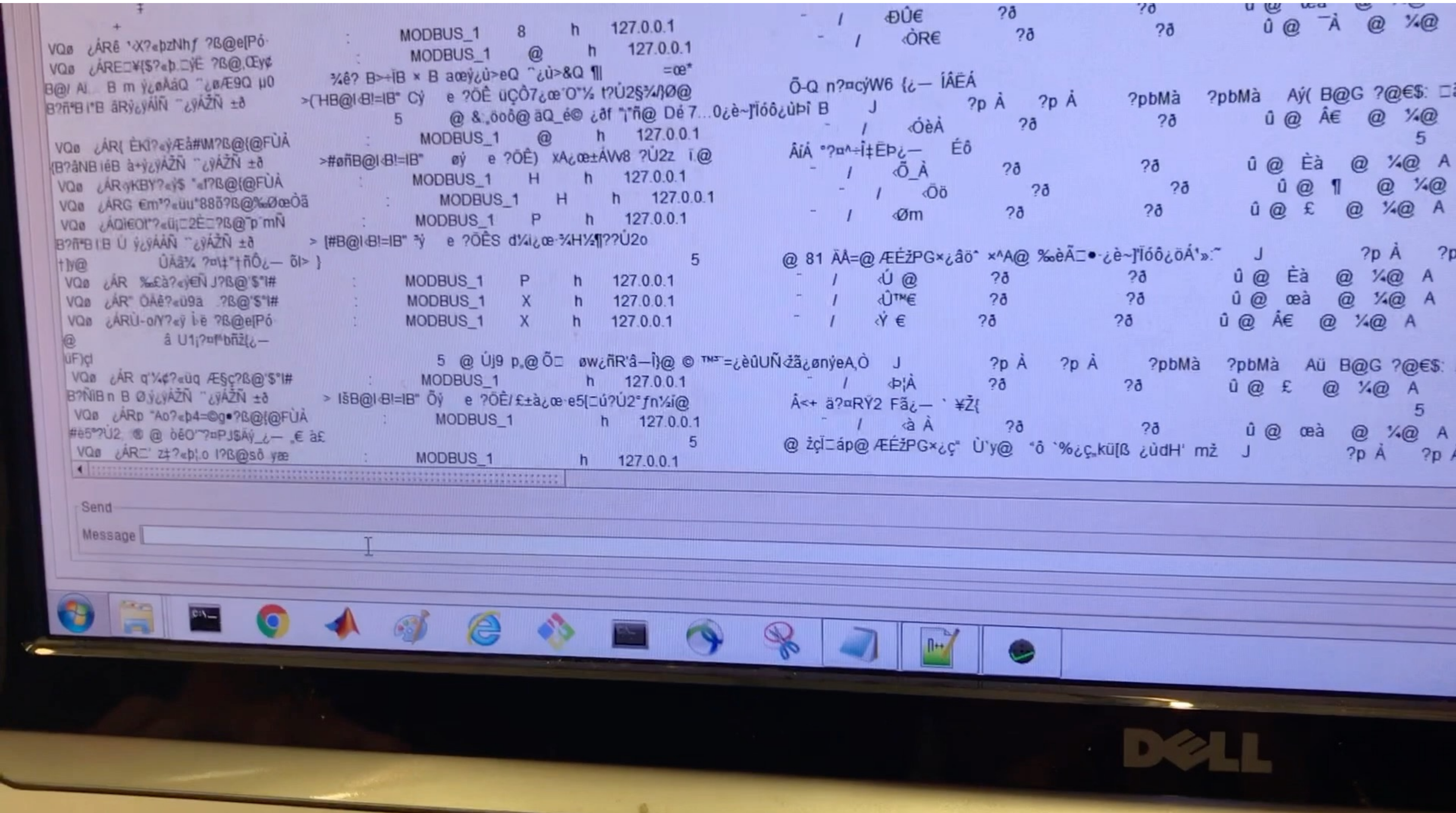


Modbus TCP/IP between CIM computer and robot

Port 30001: Direct movej commands – Autohomes_Phome

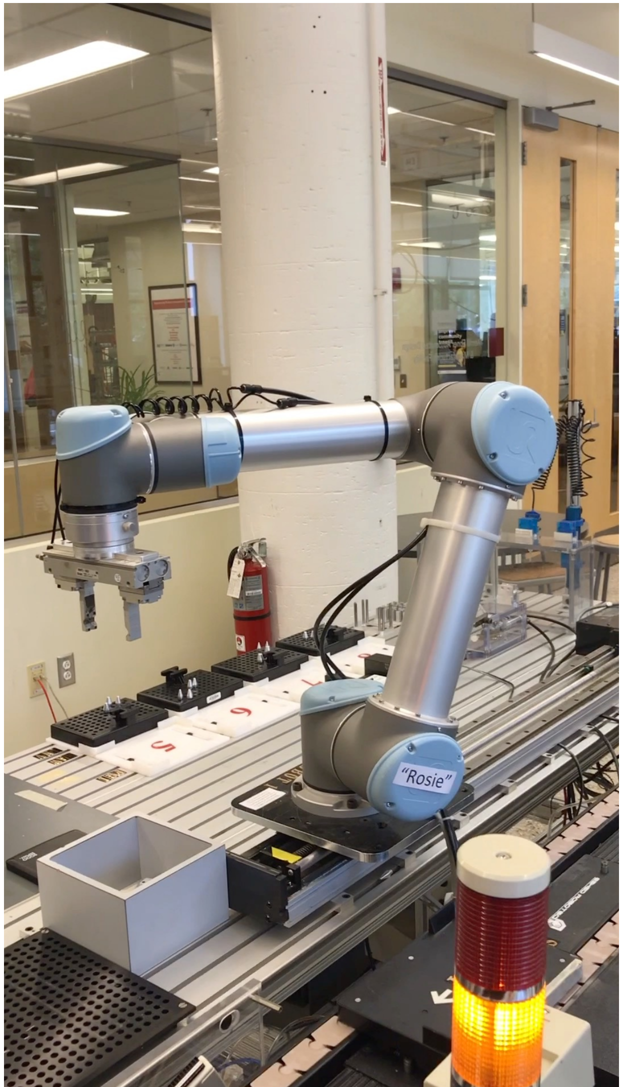
Modbus TCP/IP between CIM computer and robot

Port 30001: Direct movej commands – Phome_Homes



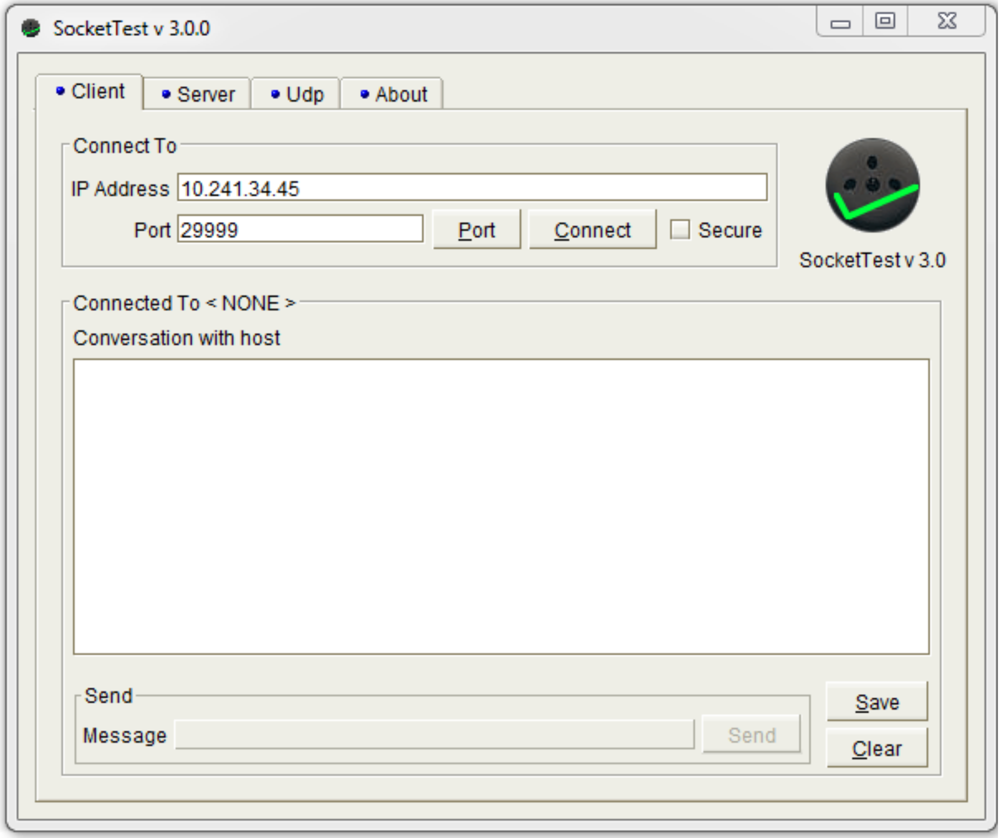
Modbus TCP/IP between CIM computer and robot

Port 30001: Direct movej commands – Phome_Homes



Modbus TCP/IP between CIM computer and robot

Commanding the robot through TCP/IP



Rosie's Dashboard Server Credentials

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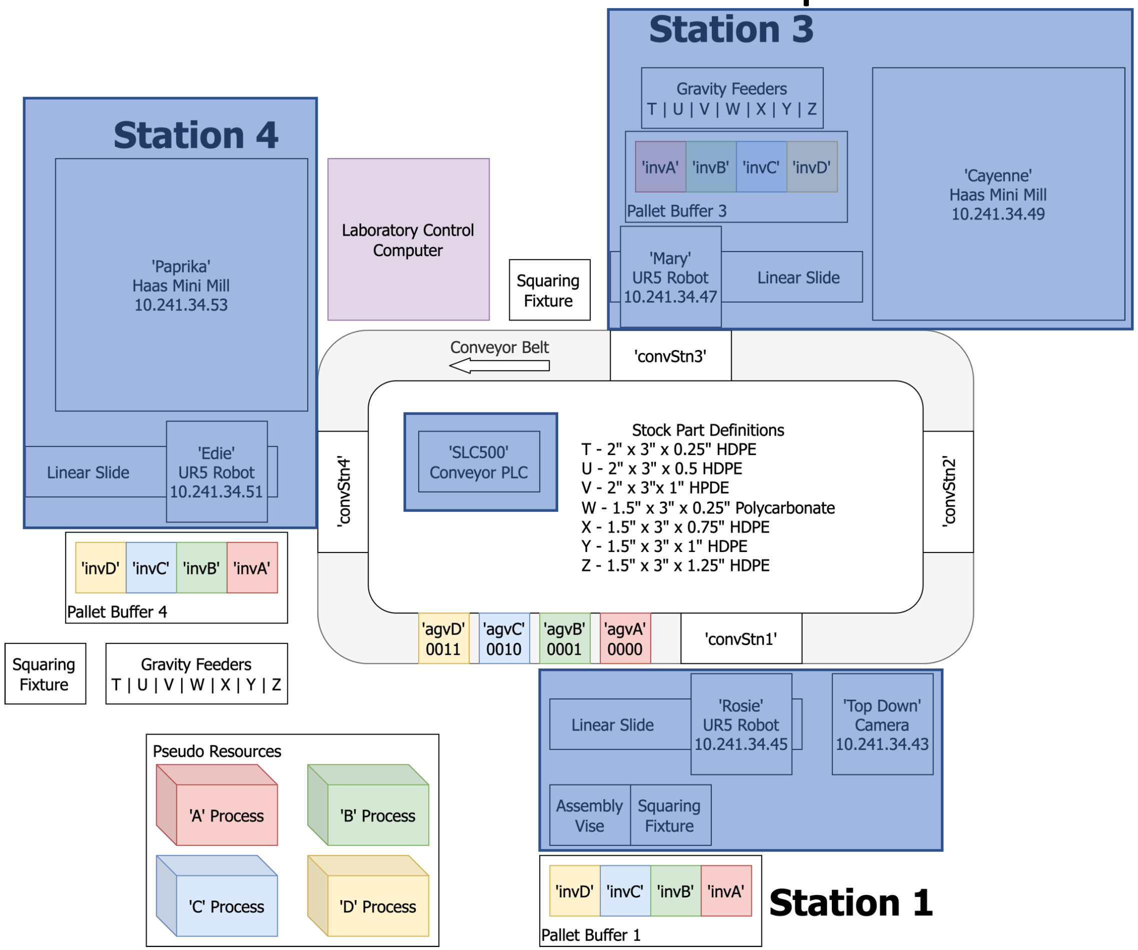
10.241.34.45	30002	100 Hz
10.241.34.45	30003	500 Hz

- Can only send commands one at a time
- What if we need a set of commands?
- What if we could send an entire file/program?

ADML system integration

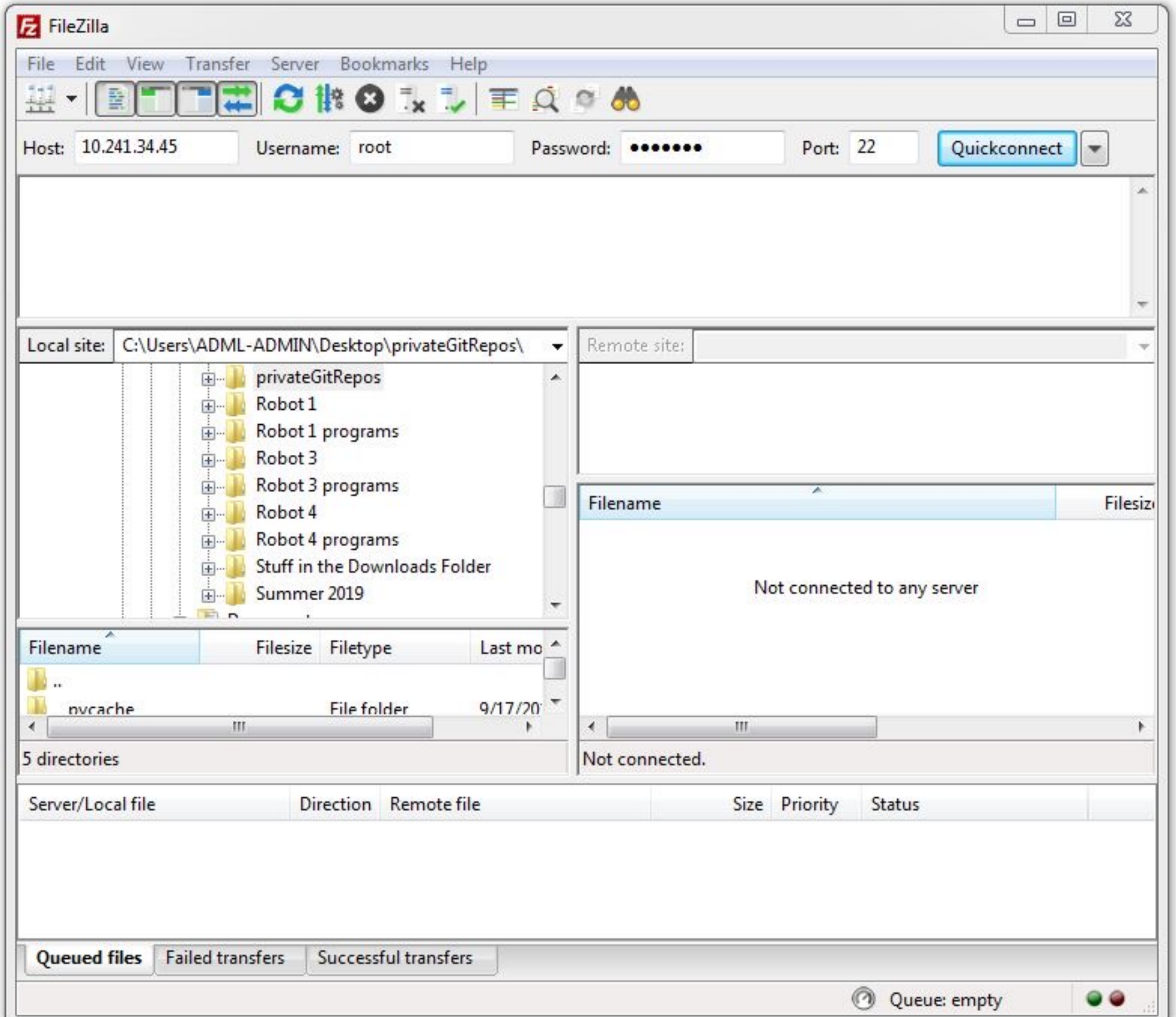
How do we connect and coordinate multiple automation systems?



Digital input/output (I/O) **Communication protocols** **File transfer protocols**

These three are used widely in industry to share complex files between automated sub-systems

Secure file transfer protocol (SFTP)



UR5 Information
Username: root
Password: easybot
Port: 22

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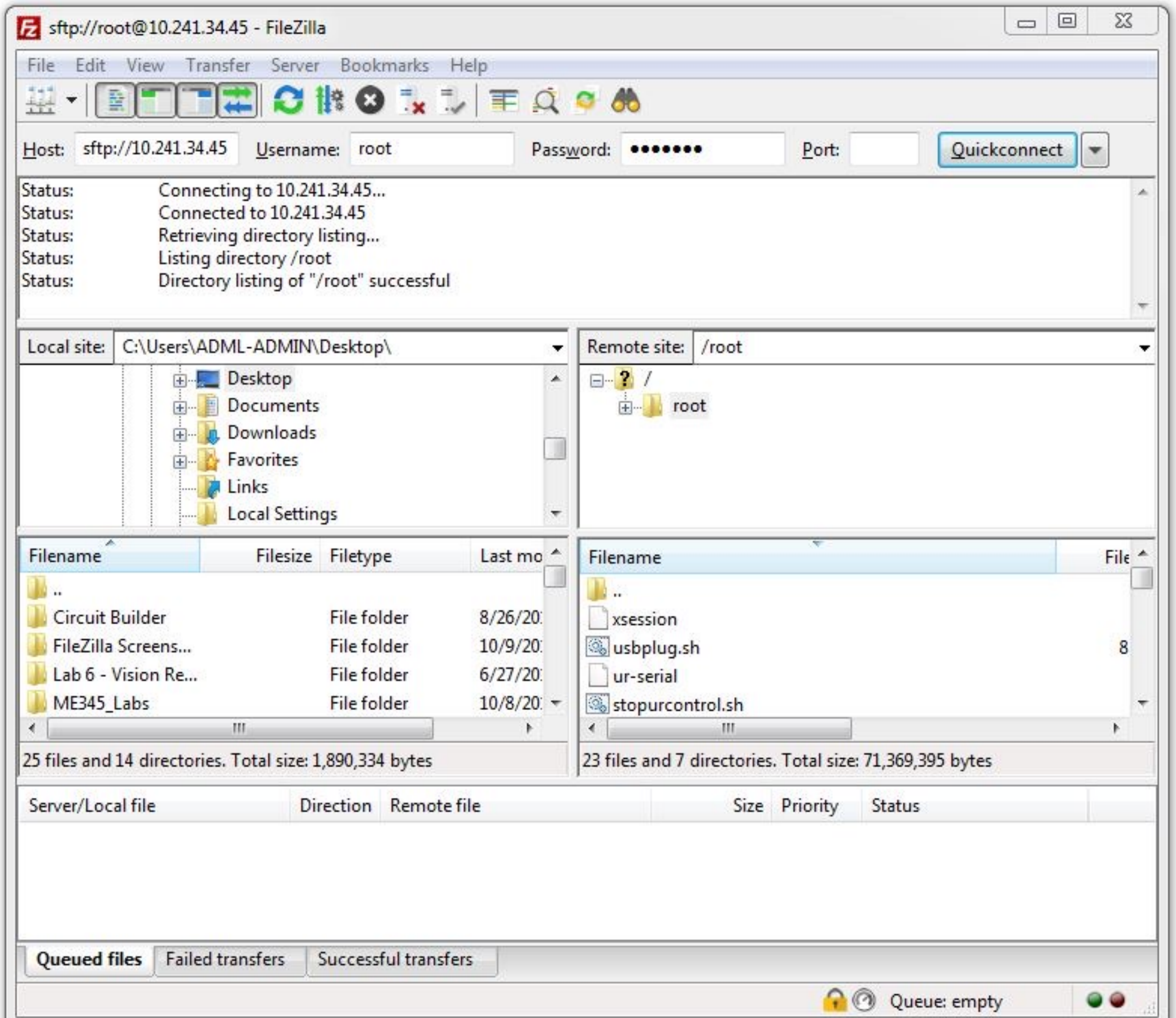
Secure file transfer protocol (SFTP)



Primarily used

1. To transfer files between robots and computers (and shared drives)
2. By CIM computer to view specific UR5 programs

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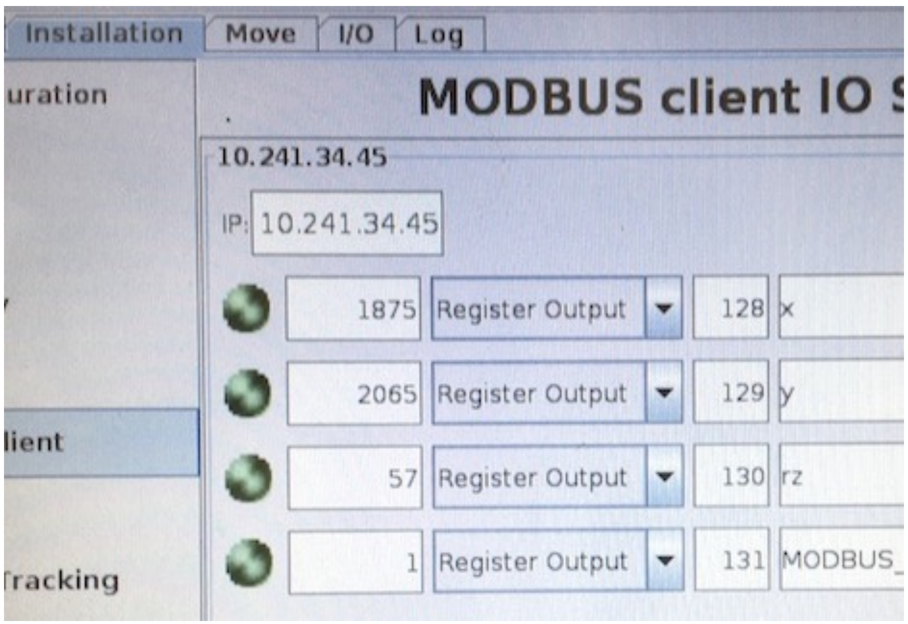
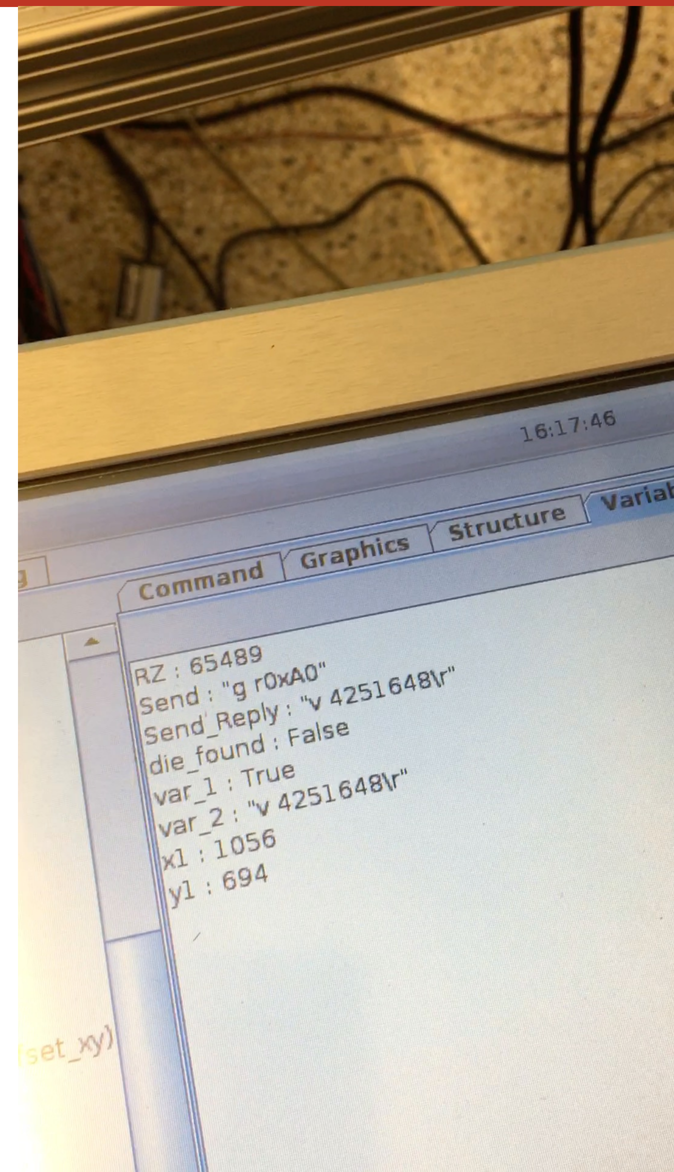
Camera integration in ADML

1. Files will be transferred to the robot via SFTP
2. TCP commands will be used to run robot program from PC (note: for this program, TCP commands are sent from the camera (master) to the robot (slave))



What else does the robot communicate with through TCP?
Linear slide



Fourth Kahoot!

Schedule

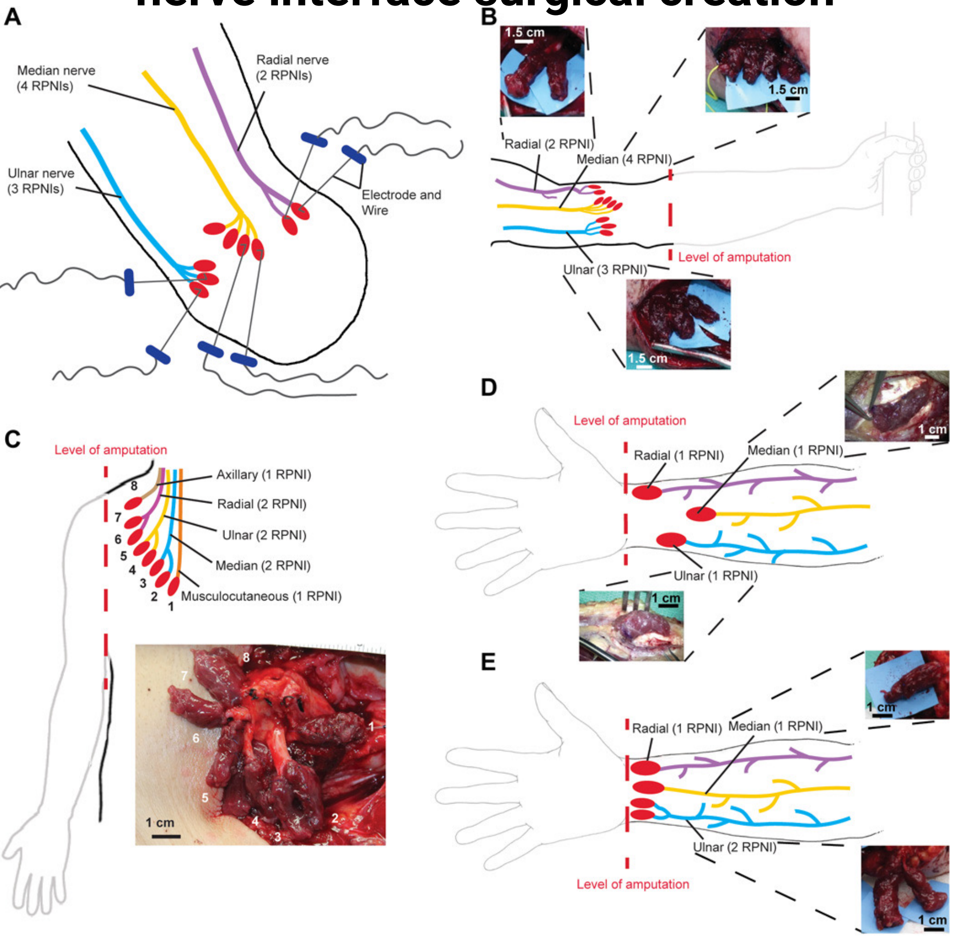
Week #	Class #	Day	Date	Location	Lecture/ Prelab Discussion Topic	Homework/Reading Due	Lab Topics	Lab Assignments Due	Project Assignments Due
7	12	Mon	10/16	EPC 207	Vision and Advanced Robotics and Integration		**Tue Lab Section** Lab 4: PLC **All Other Lab Sections** Lab 5: Vision and Advanced Robotics and Integration	**Tue Lab Section** Lab 3: Robotics 2 Report due Online before beginning of lab Pre-lab 5: Vision and Advanced Robotics and Integration Online 3 days prior to Lab 5 at 5:00 pm **All Other Lab Sections** Lab 4: PLC Report Online before beginning of lab Pre-lab Lab 6: CIM I due Online 3 days prior to Lab 6 at 5:00 pm	**All Lab Sections** In-class Pre-proposal Product Design Review Presentations delivered in class (5 minutes) & Machined prototypes - Due in class in person on Wed 10/18 Pre-proposal Product Design Presentation files - Due Online by Wed 10/18 at 11:59 pm Project Proposal - Due Online by Fri 10/20 at 11:59 pm **All Lab Sections Except for Tue** Project machine tending and assembly robot programs (part of Lab 5 in lab work)
	13	Wed	10/18	EPC 207	Pre-proposal product design review presentations (5 minutes each) (Bring machined prototypes to class) CIM I and CIM II Pre-lab Lecture (1 Group) following presentations				
8	14	Mon	10/23	EPC 207	Additive Assembly Lab (AAL) Research Presentation by AAL PhD Students	HW #3 (Scheduling) - Due Online Wed 10/25 before lecture	**Tue Lab Section** Lab 5: Vision and Advanced Robotics and Integration **All Other Lab Sections** Lab 6: CIM I	**Tue Lab Section** Lab 4: PLC Report Online before beginning of lab Pre-lab Lab 6: CIM I due Online 3 days prior to Lab 6 at 5:00 pm **All Other Lab Sections** Lab 5: Vision and Advanced Robotics and Integration Report Online before beginning of lab Pre-lab Lab 7: CIM II due Online 3 days prior to Lab 7 at 5:00 pm	**Tue Lab Section Only** Project machine tending and assembly robot programs (part of Lab 5 in lab work)
	15	Wed	10/25	EPC 207	SPC Pre-lab Lecture (1 Group)				

More system integration examples

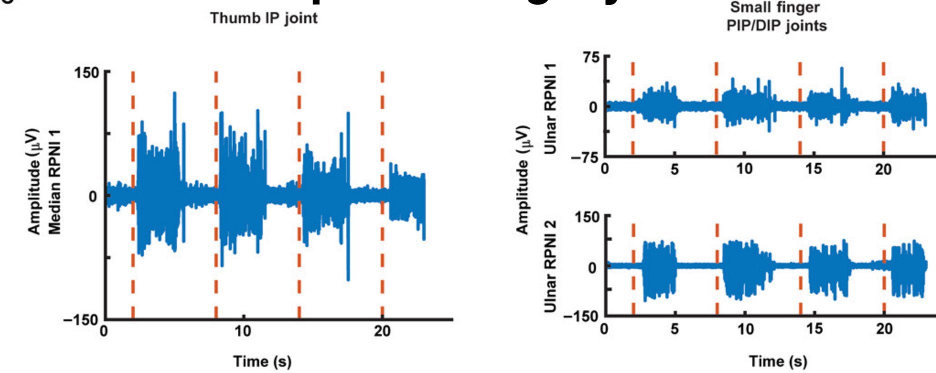
A sci-fi example (Avatar)

A medical example

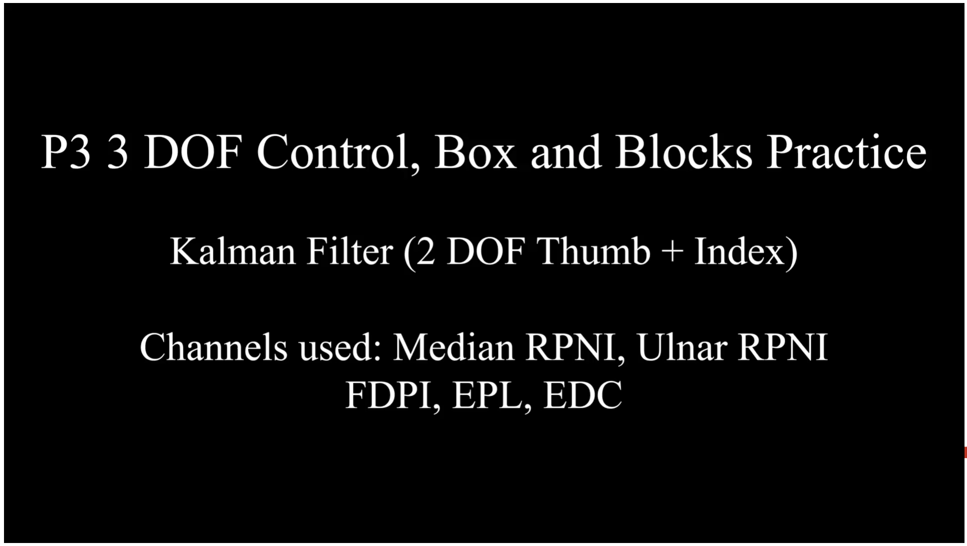
Electrode insertion and anatomical illustrations of regenerative peripheral nerve interface surgical creation



Human generated nerve signals to specific finger joints



Human-controlled robotic hand



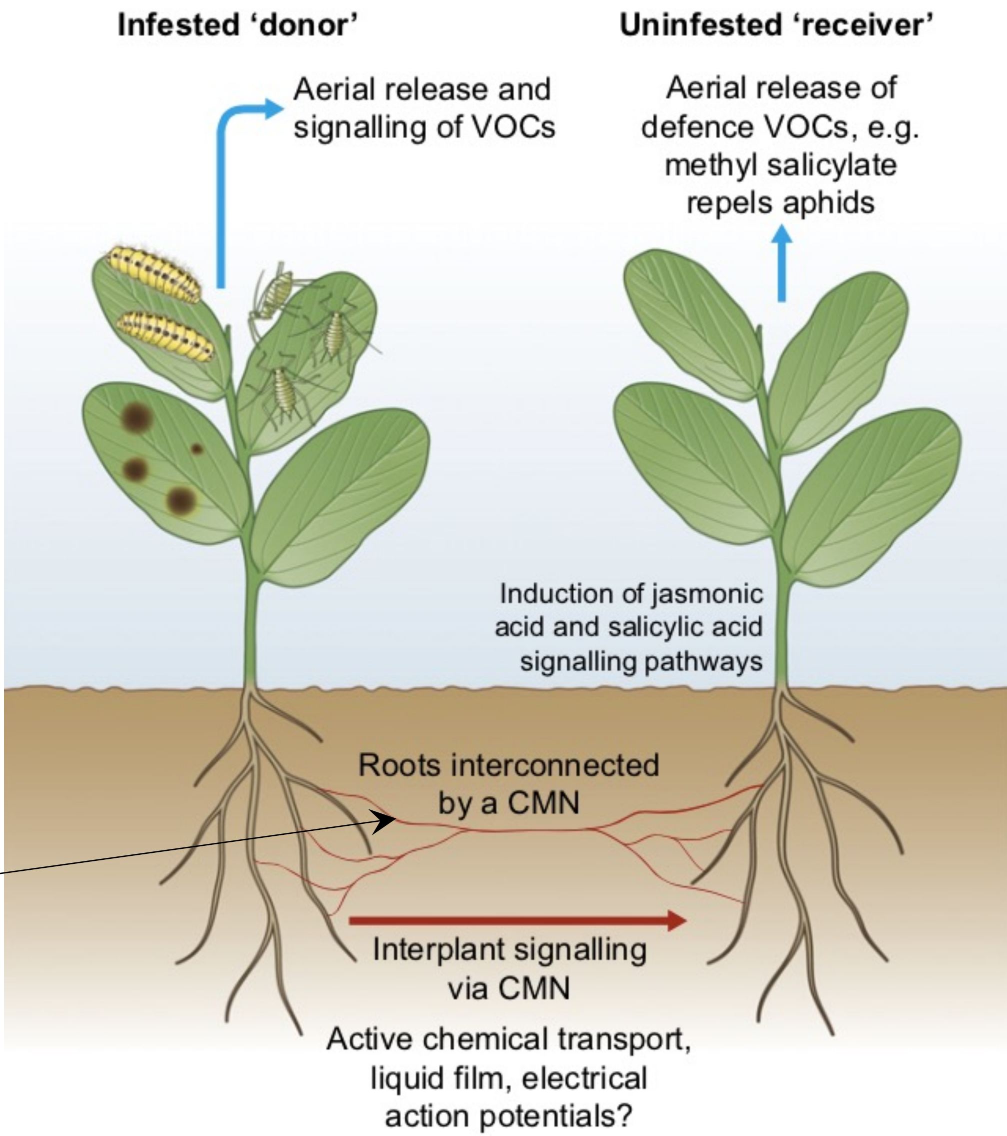
P. Vu et al. *Sci. Transl. Med.* 2020

An example from biology

Defense from phloem-sucking insects

- VOCs – volatile organic compounds
- CMN – common mycelial network (e.g., active chemical transport, passive liquid surface transport, electric potential)

Typically a fungal network



D. Johnson and L. Gilbert. *New Phytologist*. 2014

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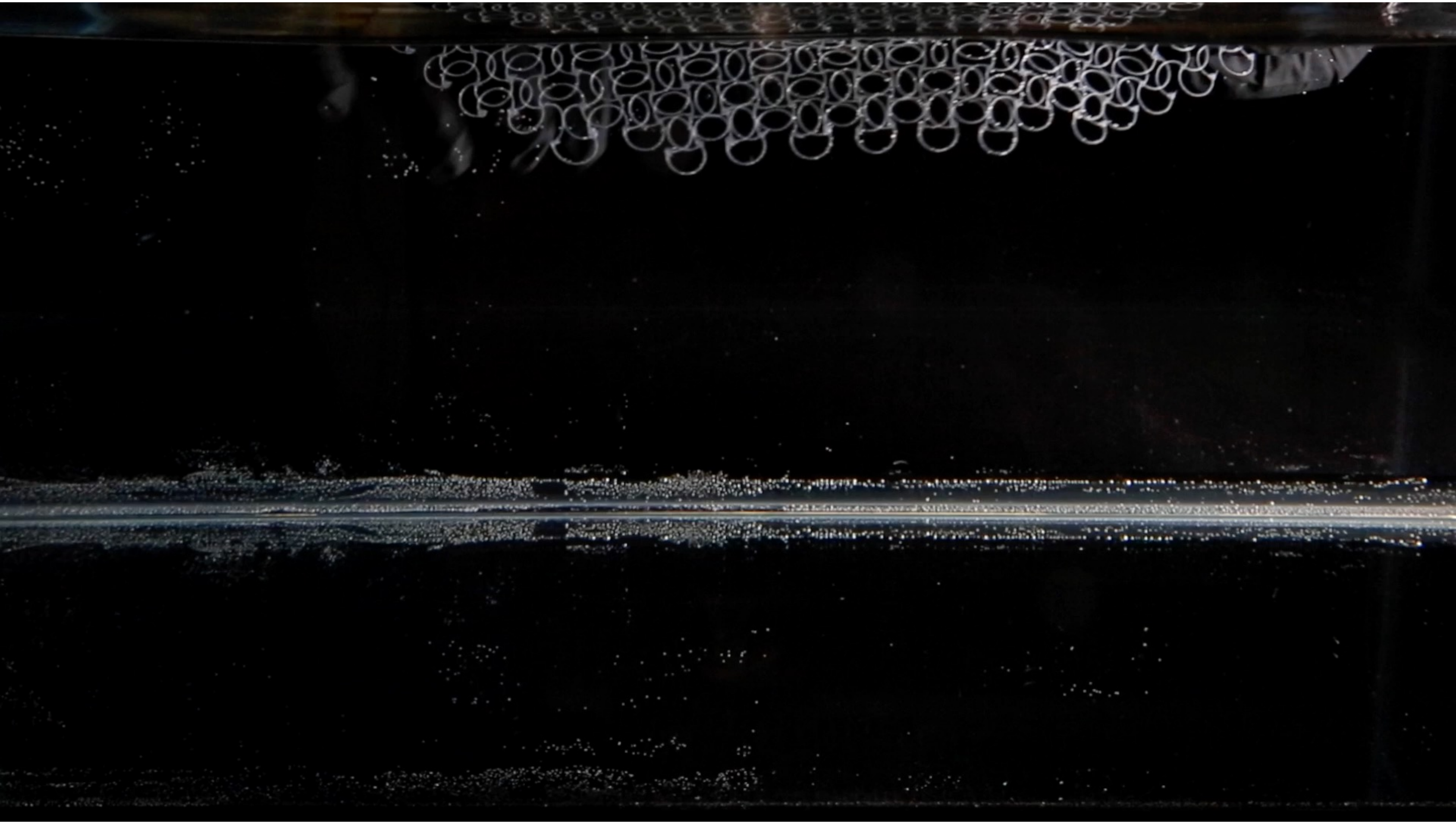
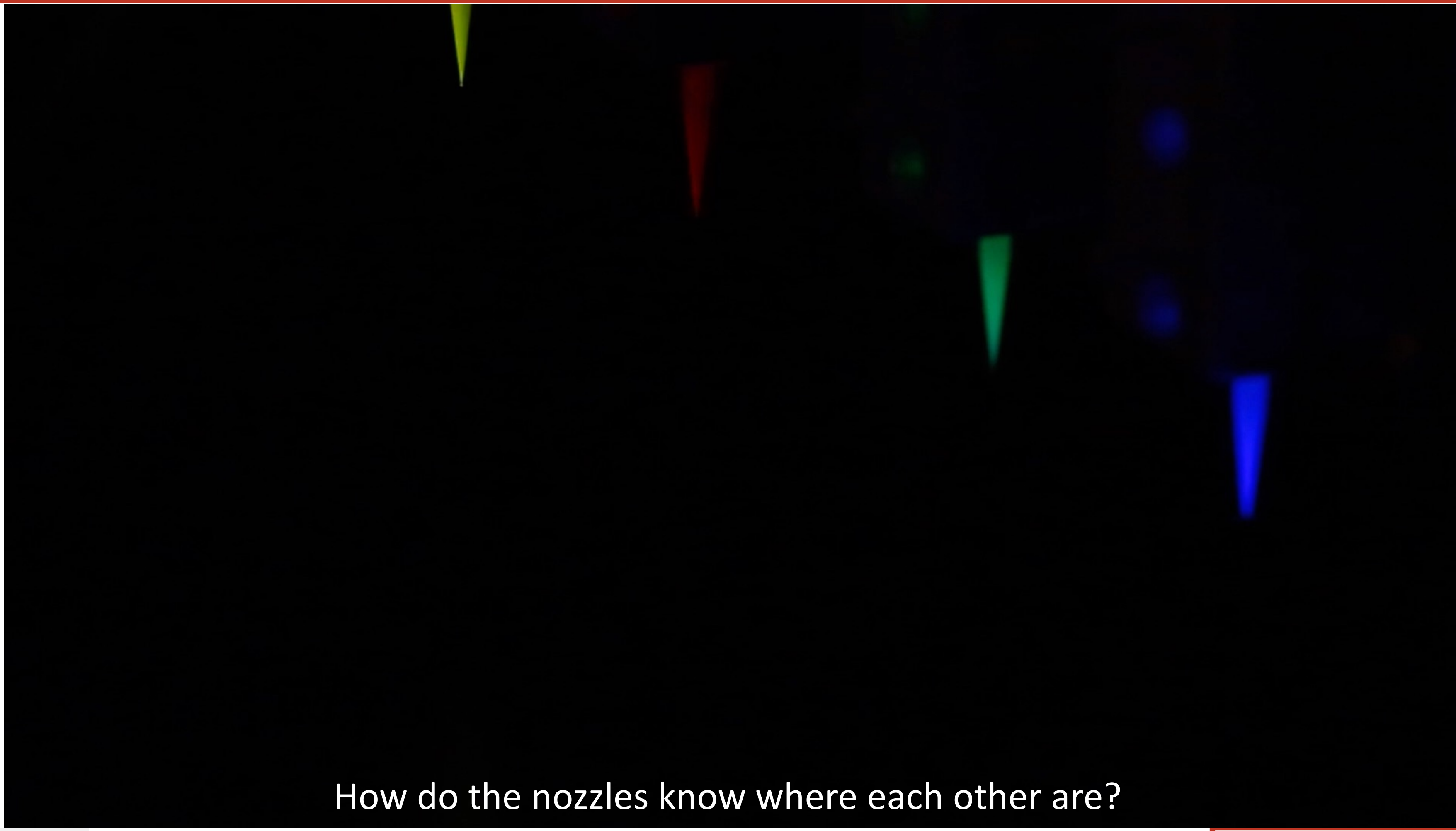
Multi-material 4D printed lattices



Boley, van Reese, et al. *PNAS. October 2019.*

(Video courtesy of Lori Sanders/Harvard University)

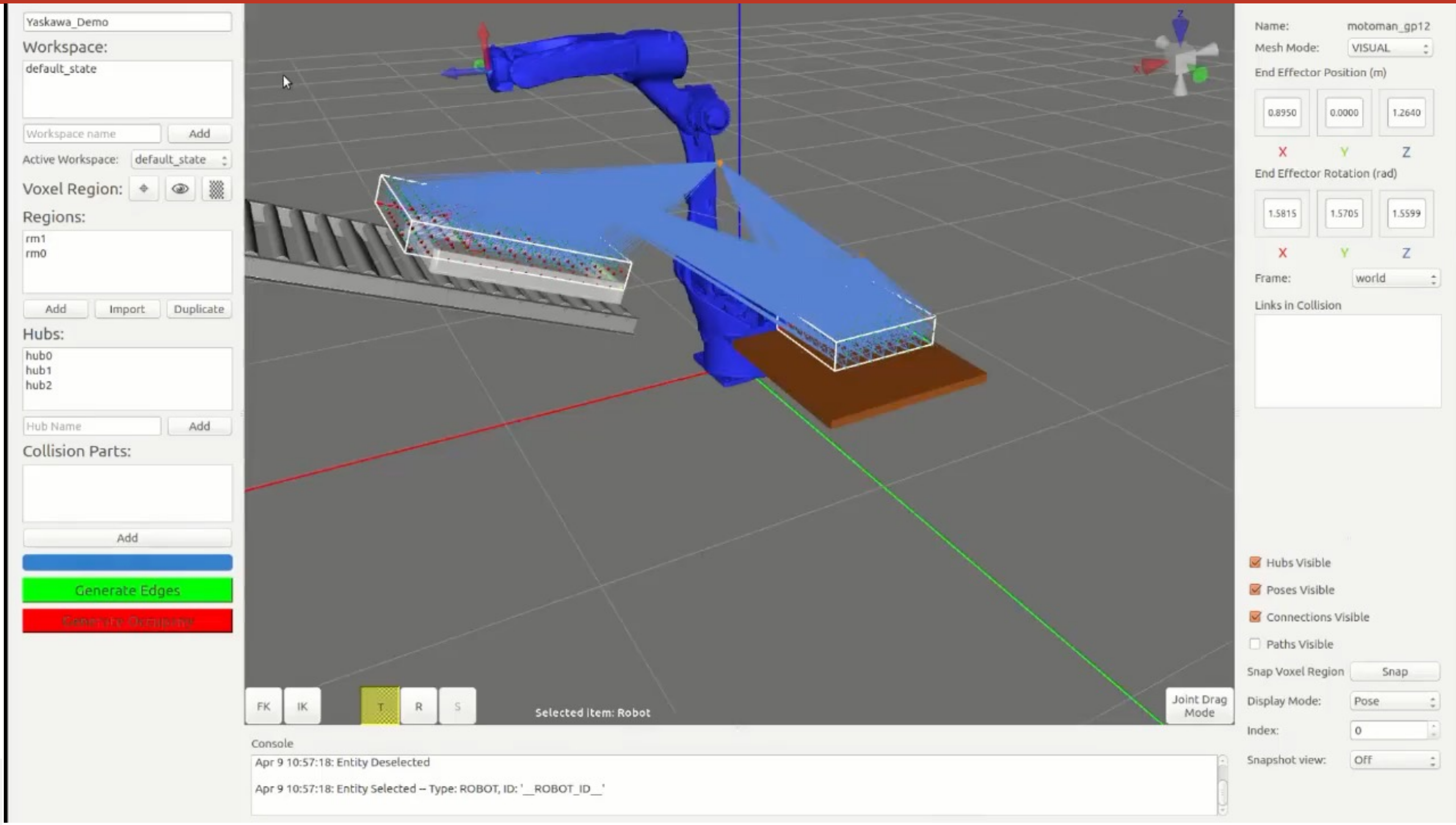
Multi-material 4D printed lattices



Boley, van Reese, et al. *PNAS. 2019.*

(Video courtesy of Lori Sanders/Harvard University)

Dynamic path planning example



Real Time Robotics: https://rtr.ai