Using the BeagleBone Black and Node-RED to Teach IIoT Concepts

Outline

- Grant
- History of I4.0
- IIoT Course
  - Controllers
  - Programming
  - Hands on Labs
- Outcomes

By
Richard Hartmann, Ph.D.

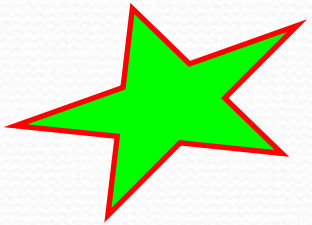
Preparing Robotics Technicians for Industry 4.0

NSF ATE Grant #2000904

Objectives

- Increase capacity to prepare technicians for employer needs
- Increase number of students in program
- Expand awareness and provide pathways for high school students
- Disseminate project findings and best practices

- Increase quality of future technicians with new class!



New class

Industrial Internet of Things

- Introductory class (No prereqs!)
- Hands on
- Draw high school students into the field
- Stimulate interest in automation/manufacturing field
- Instill passion for technology which will encourage completion of degree

Hands on IIoT Trainer

- **Goals**
  - Fun, interactive to capture interest of students
  - Simulate industrial processes
  - Demonstrate key components of I4.0 technologies: sensors, communications, data, security
  - Low cost / Low footprint / flexible / expandable
    - Something local high schools can afford to implement or students can purchase on their own

Brief History of The Industrial Revolution

I 1.0

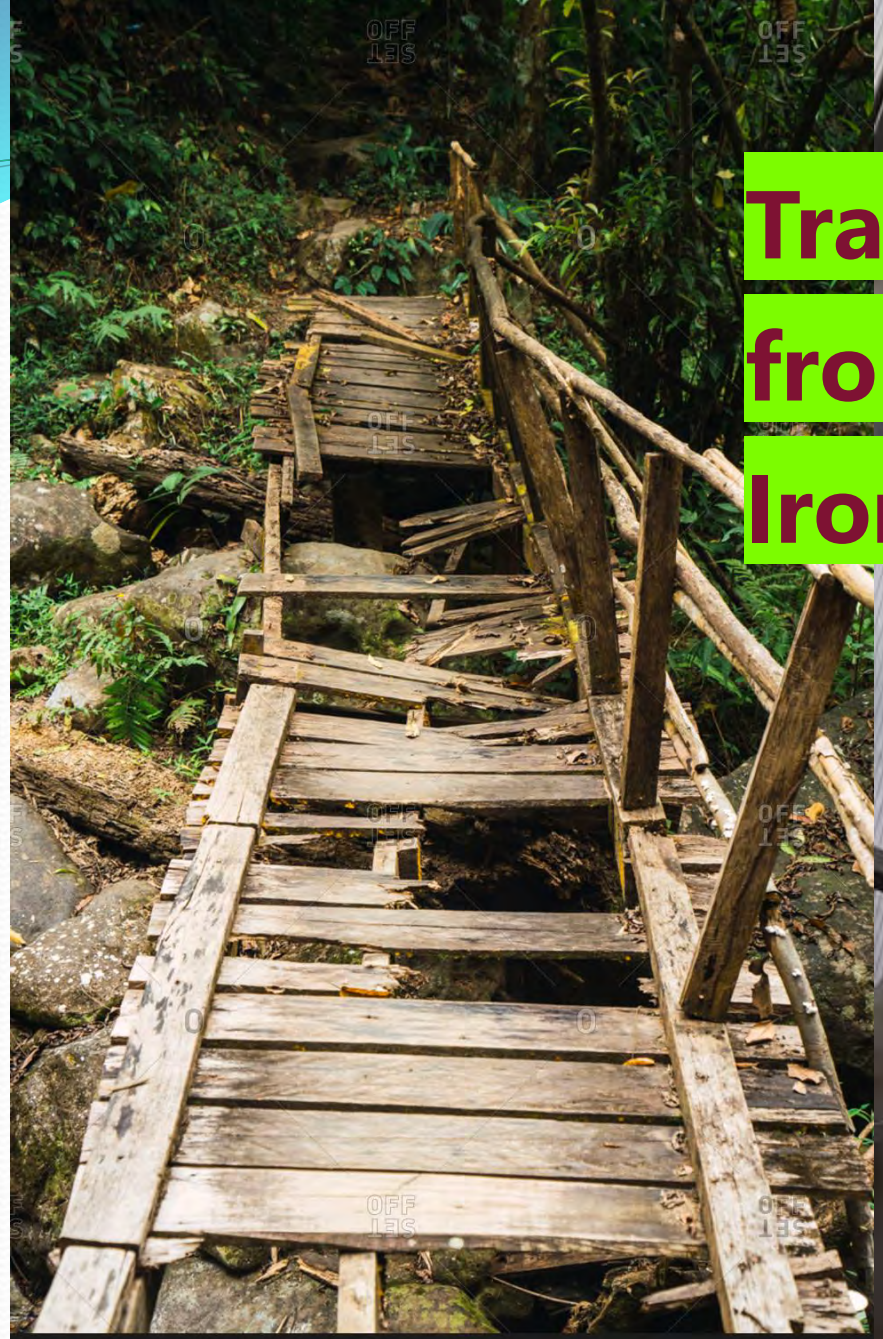
Water & Steam Power
Iron and Steel

- Started Late 1700's into 1800's

The Industrial Revolution - 1.1

- Transition to Steam Power

Transition from wood to Iron and Steel



The Industrial Revolution

2.0

Mass Production
Assembly Line
Electricity

- Started Late 1800's to Early 1900's

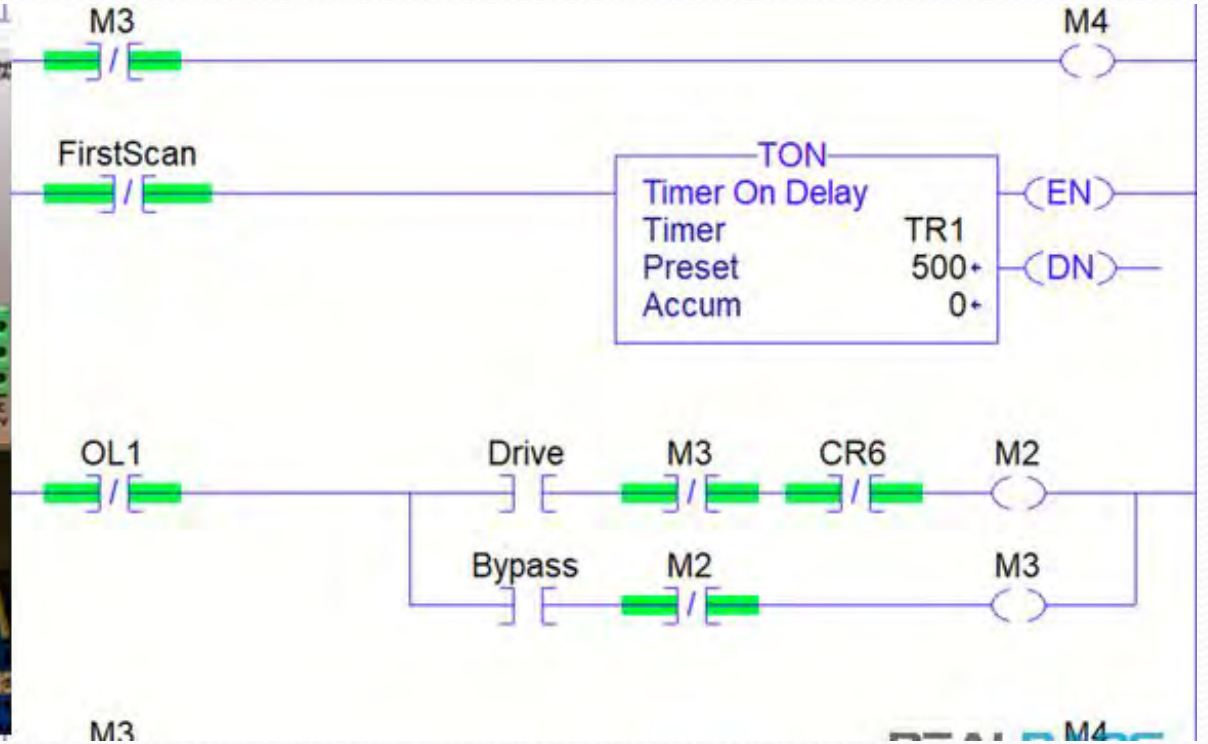
The Industrial Revolution

I3.0

Automation (PLC)

Programmable Logic Controller

- Started 1969



Automated Control Terminology

Sensor – a device that measures a physical attribute such as temperature, pressure, speed, and converts it into a form that can be read by controller device or sent to an edge device for processing

Controller – a device that can read information from sensors and inputs and send instructions to an actuator.

Actuator – Something that can be given an instruction(power) and it will perform some physical response, motor, speaker, light, etc.

The Industrial Revolution

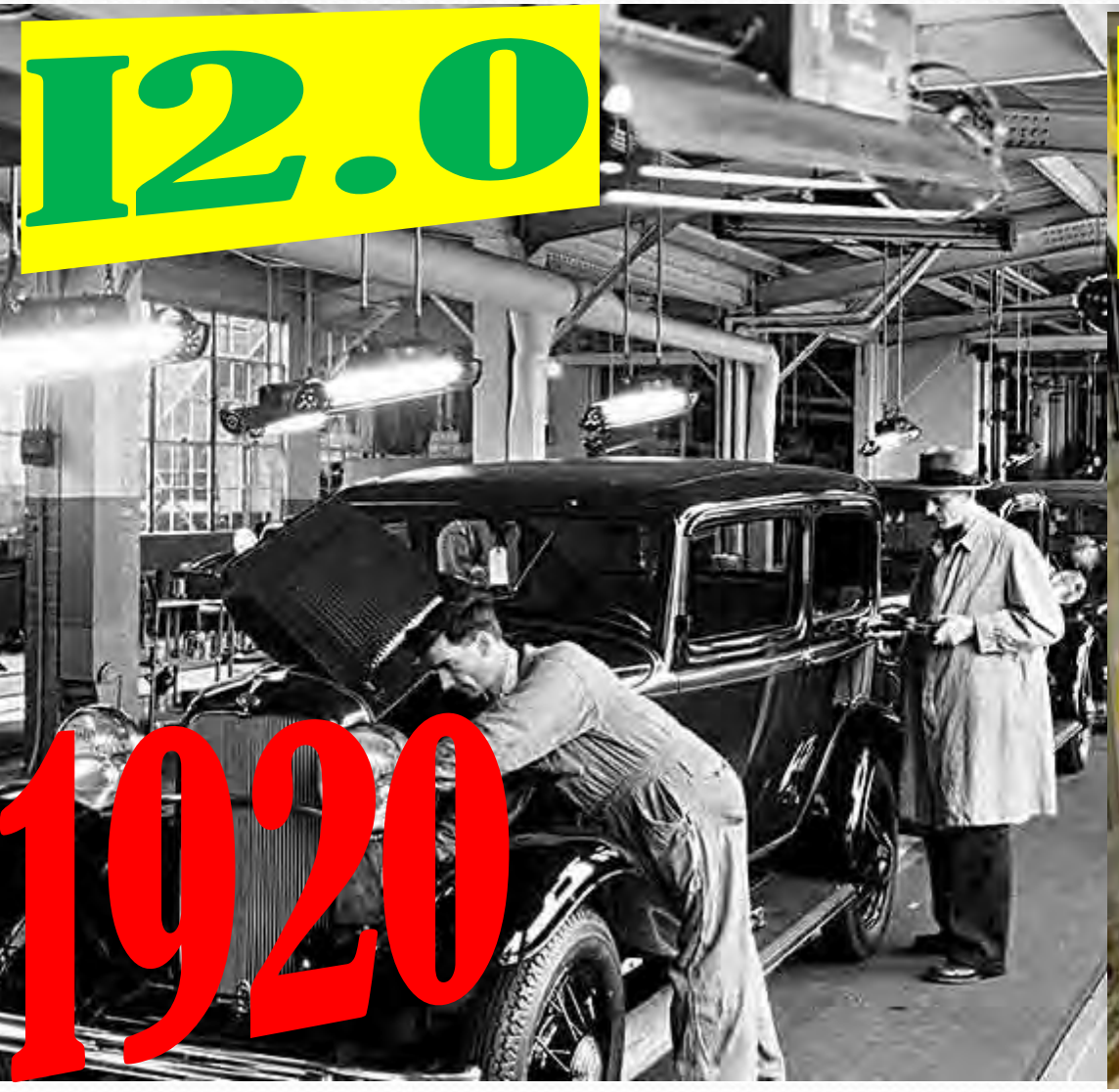
Digitization

Industrial Internet of Things

Cyber Security

- Started Late 1990

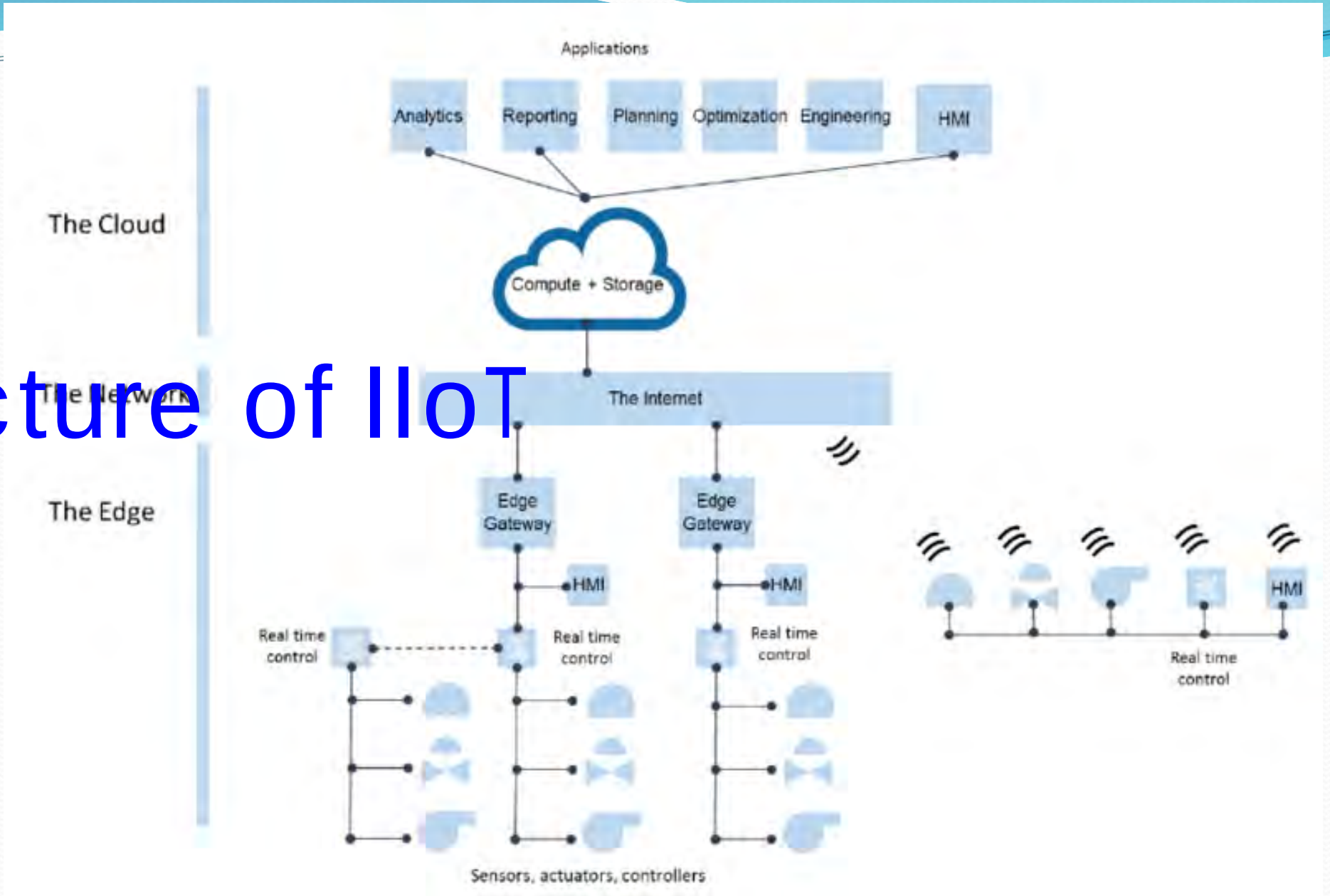
Progress



Industrial Internet of Things

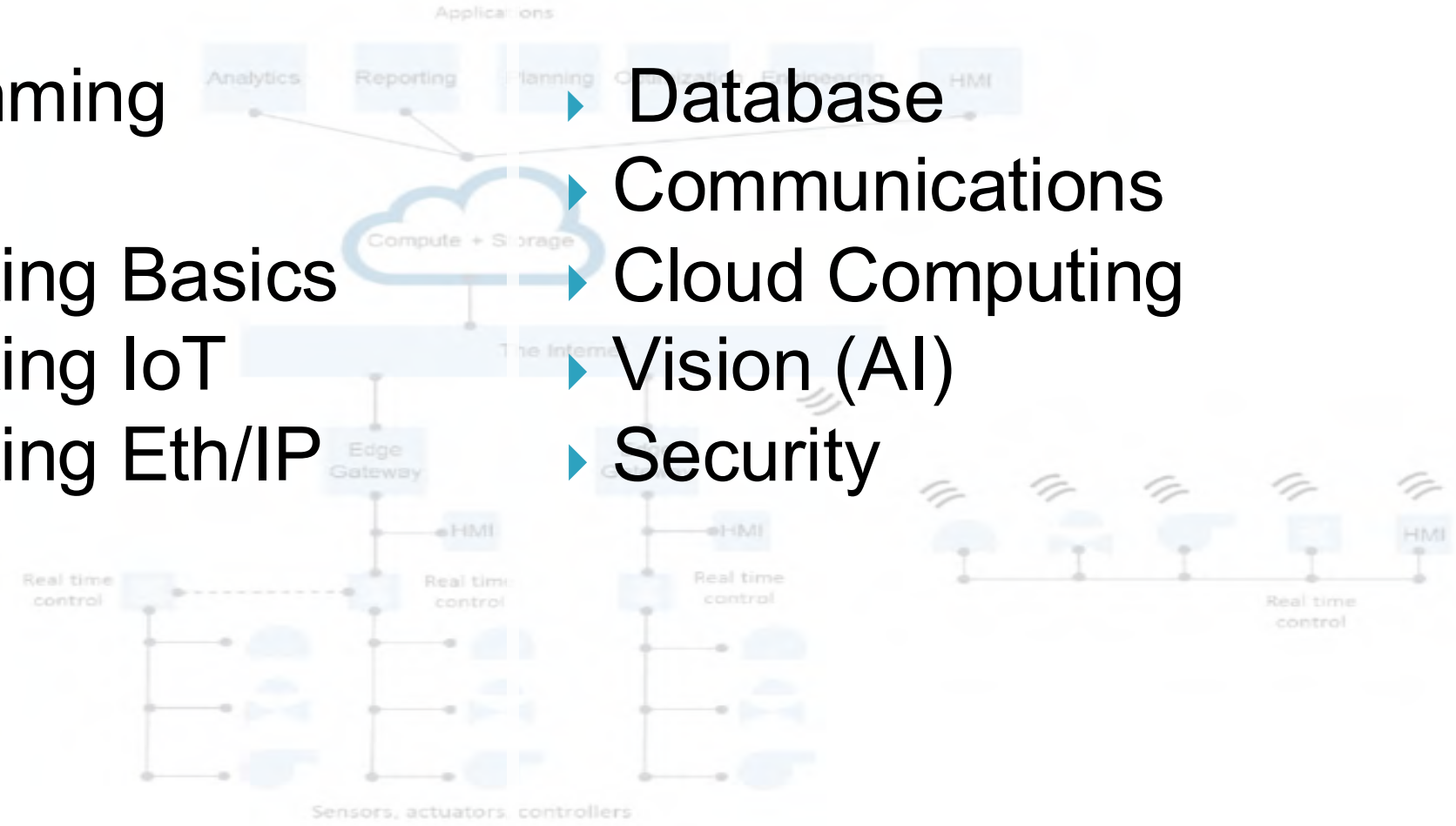
- Connecting all aspects of manufacturing through networks
  - Status of the manufacturing process is always available
  - Instructions can be sent back from virtually anywhere

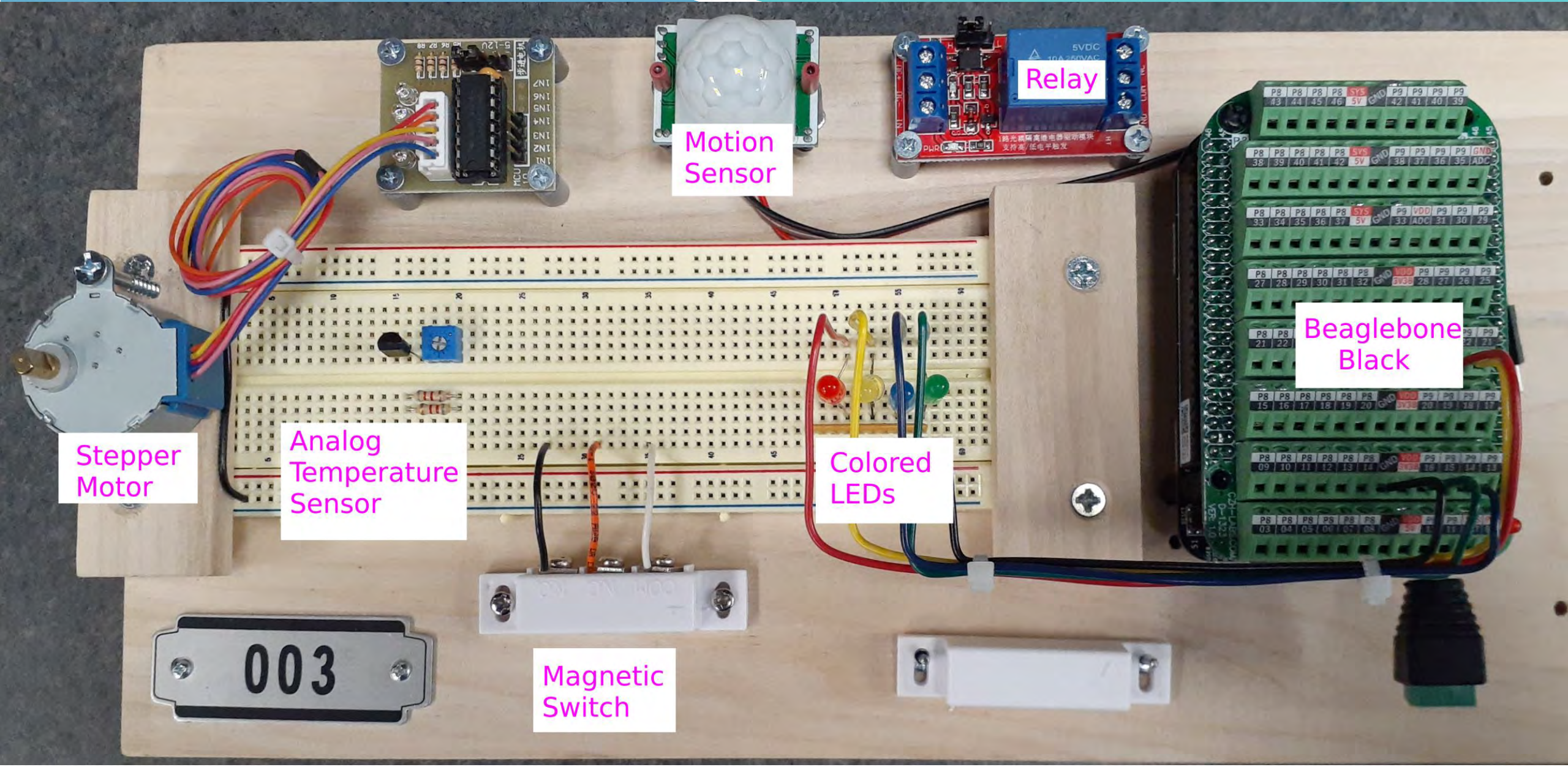
Structure of IIoT



Hands on Labs for IIoT Class

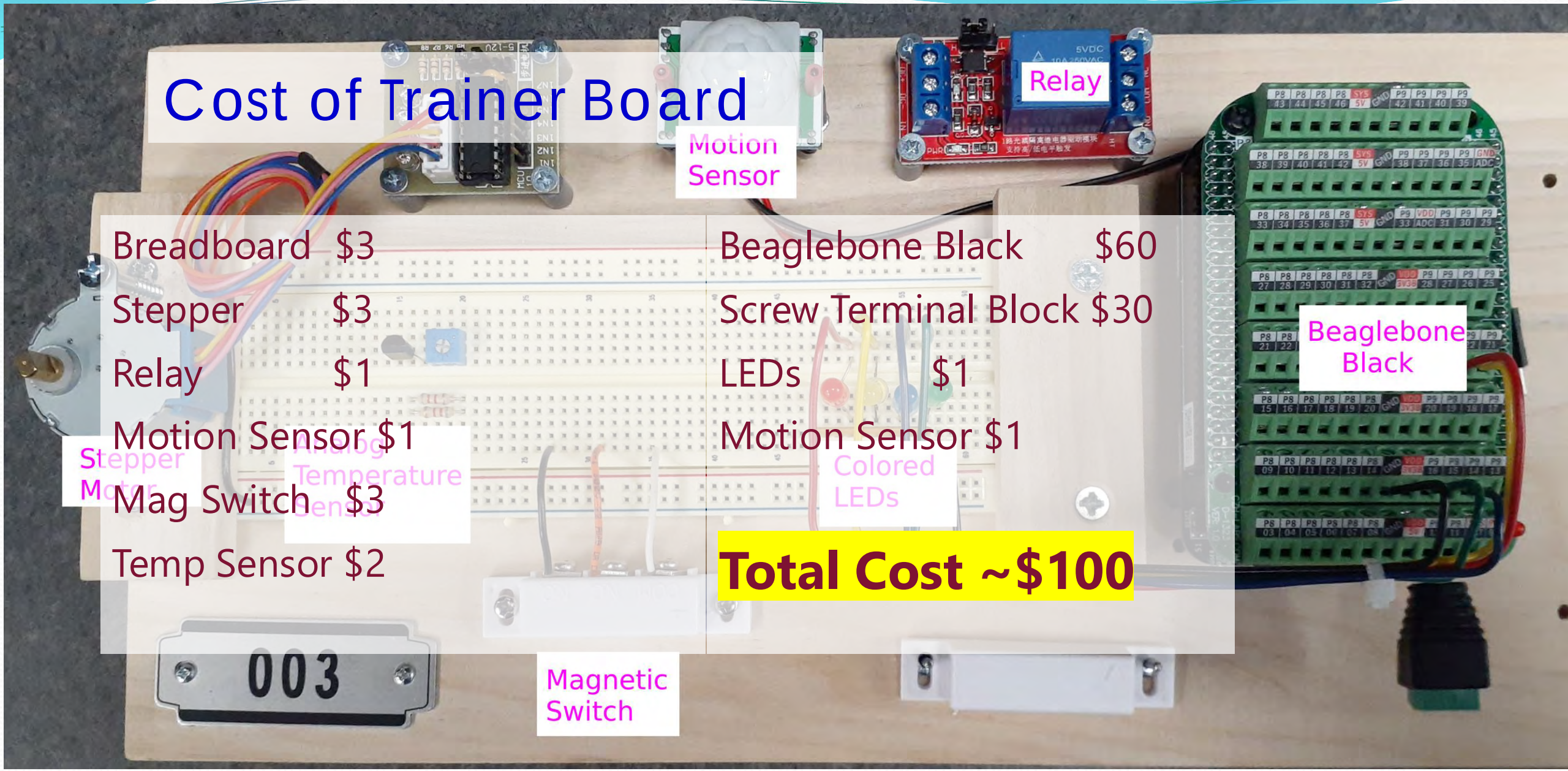
- Programming
- Binary
- Networking Basics
- Networking IoT
- Networking Eth/IP
- Inputs
- Outputs
- Database
- Communications
- Cloud Computing
- Vision (AI)
- Security





Hands on IIoT Trainer

Cost of Trainer Board



Breadboard	$3	Beaglebone Black	$60
Stepper	$3	Screw Terminal Block	$30
Relay	$1	LEDs	$1
Motion Sensor	$1	Motion Sensor	$1
Mag Switch	$3		
Temp Sensor	$2		

Total Cost ~$100

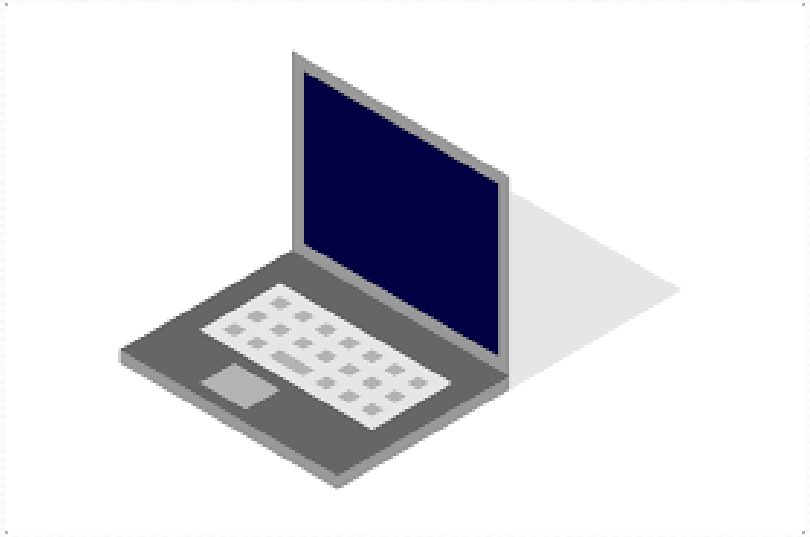
Why the Beaglebone?

Controllers

- PC
- PLC
  (Programmable Logic Controller)
- Arduino
- Raspberry Pi
- BeagleBone

PC / Laptop

- ✗ Not built for control
- ✗ No local I/O for sensors/actuators
- ✗ Too Familiar, no novelty



PLC (Programmable Logic Controller)

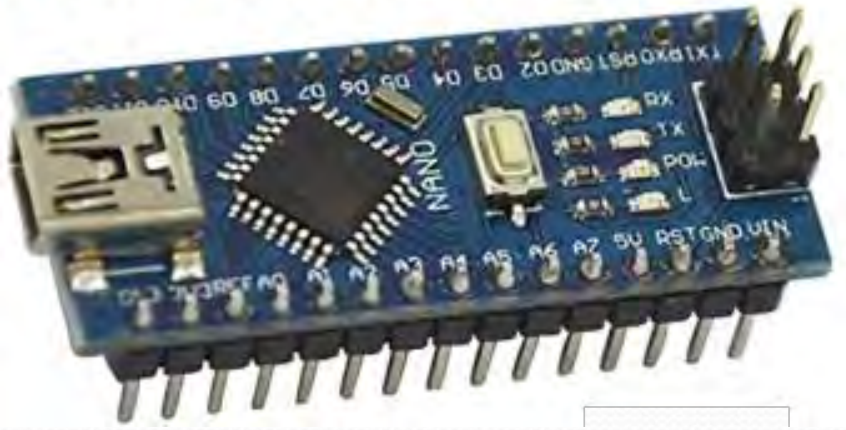
a.k.a. Industrial PC

- ✗ Already have two PLC classes, limit duplication
- ✗ Limited Internet Abilities
- ✗ Requires programming and wiring knowledge

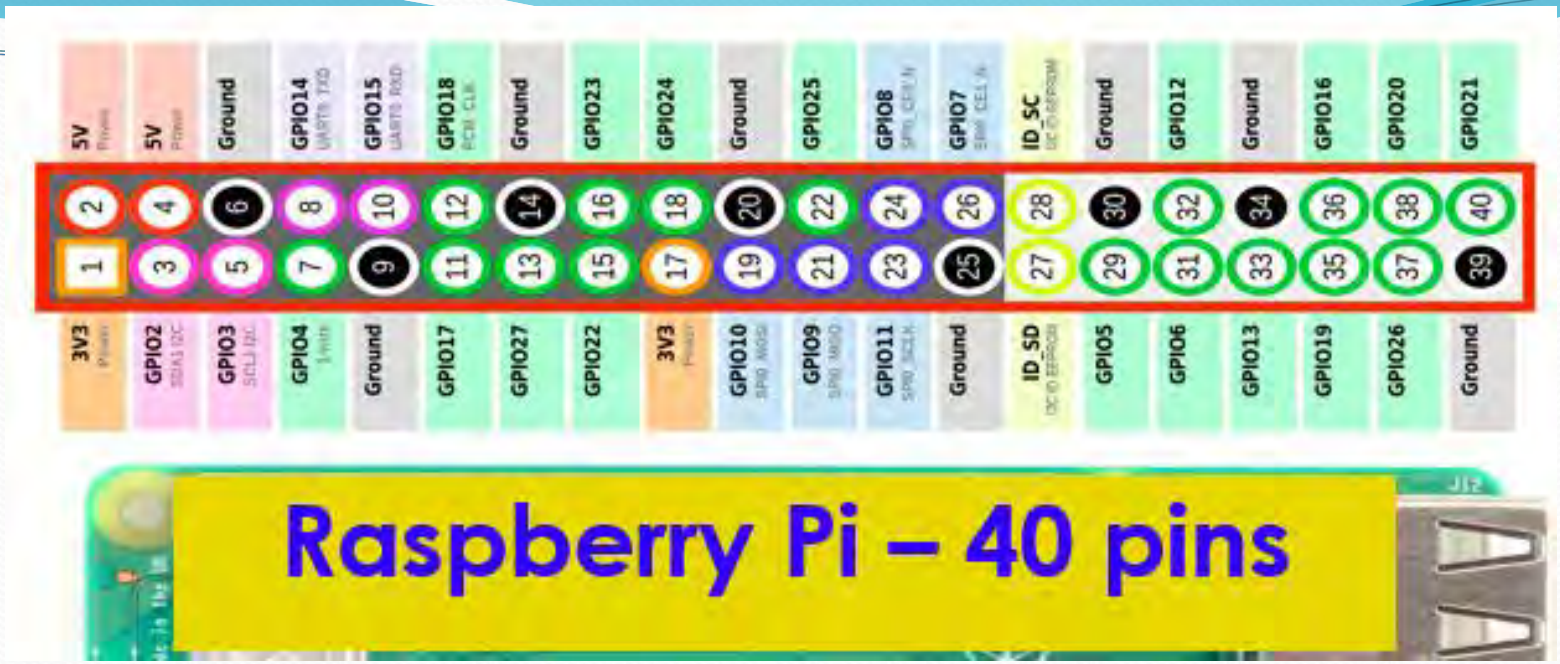
Arduino (Simple Real-time controller)

- ✗ Programming knowledge required
- ✗ none to
  limited Internet abilities
- ✗ Limited I/O

Arduino Nano $10

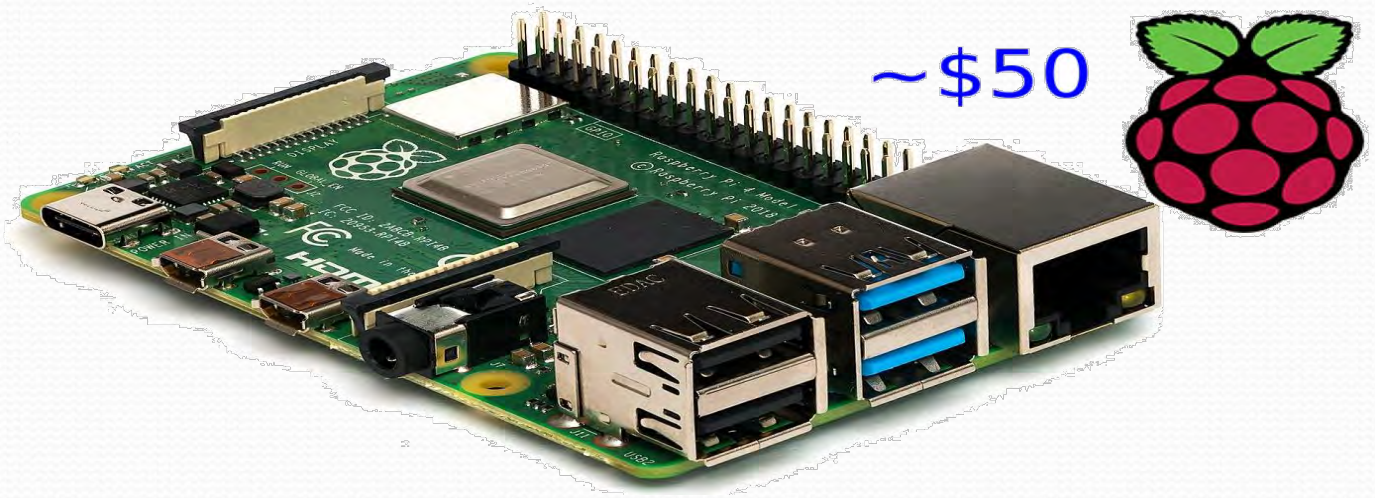


Raspberry Pi
(Digital Controller – not real-time)



✗ Limited I/O

✗ No Analog Input



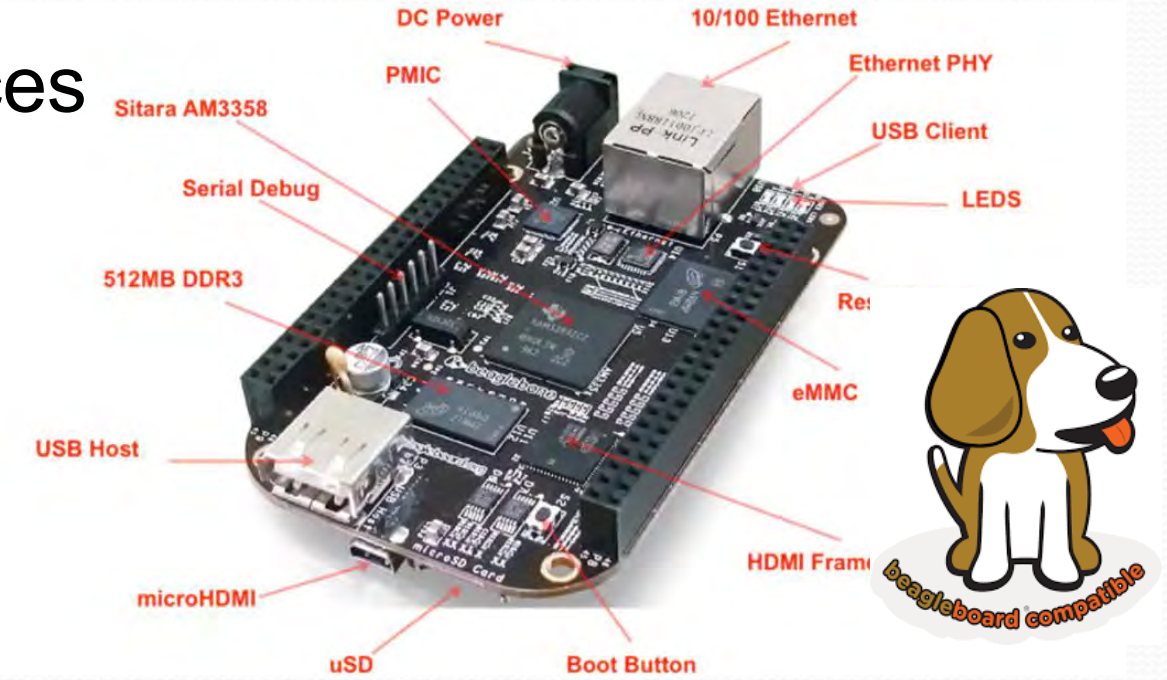
Beaglebone or Beaglebone AI

(two real-time companion processors)

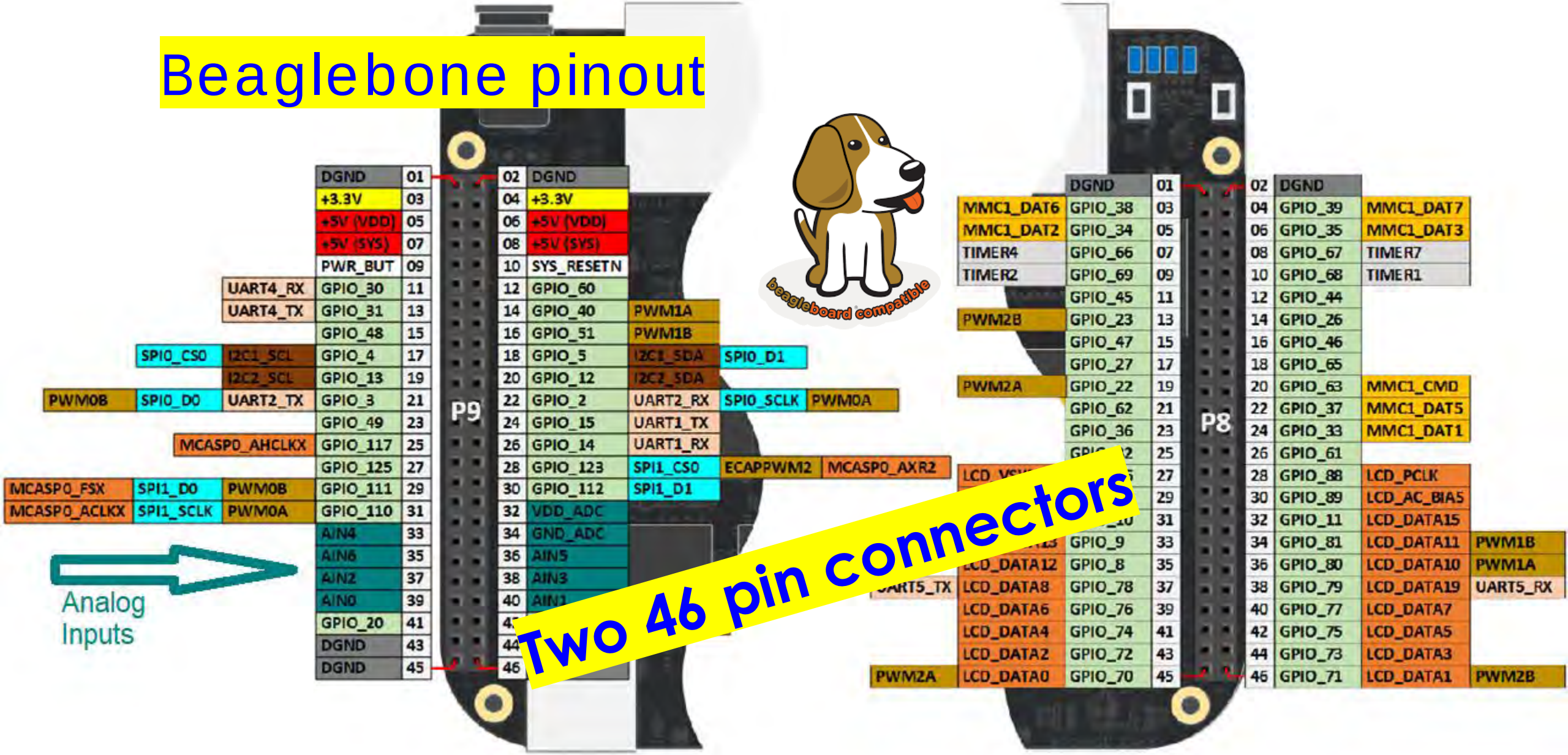
- Lots of I/O Including Analog

~$60

- Lots of Programming Choices
- Great Network Abilities
- Real-time capabilities

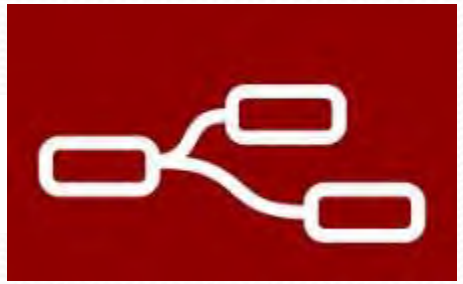


Beaglebone pinout



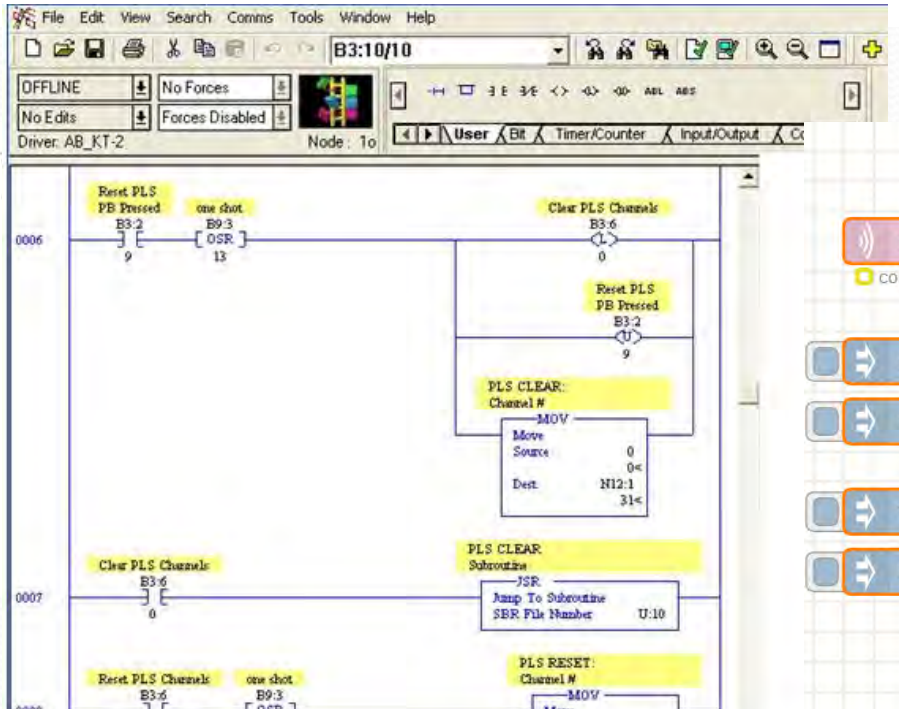
Programming Languages

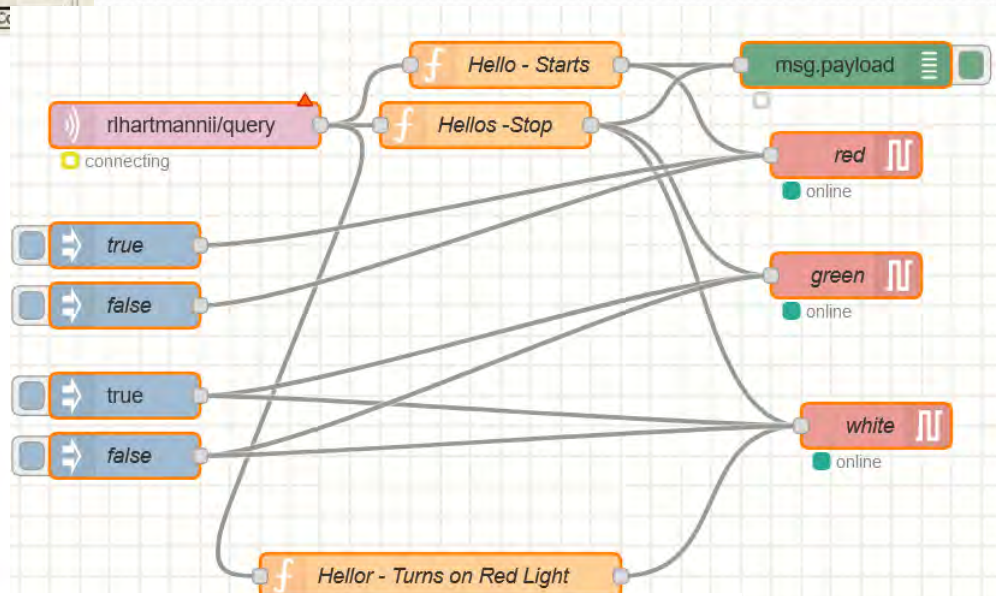
Text based or Graphical



```
if(msg.payload==="Hello"
    msg.payload=1;
}
else
{
    msg.payload=0
}

return msg;
```

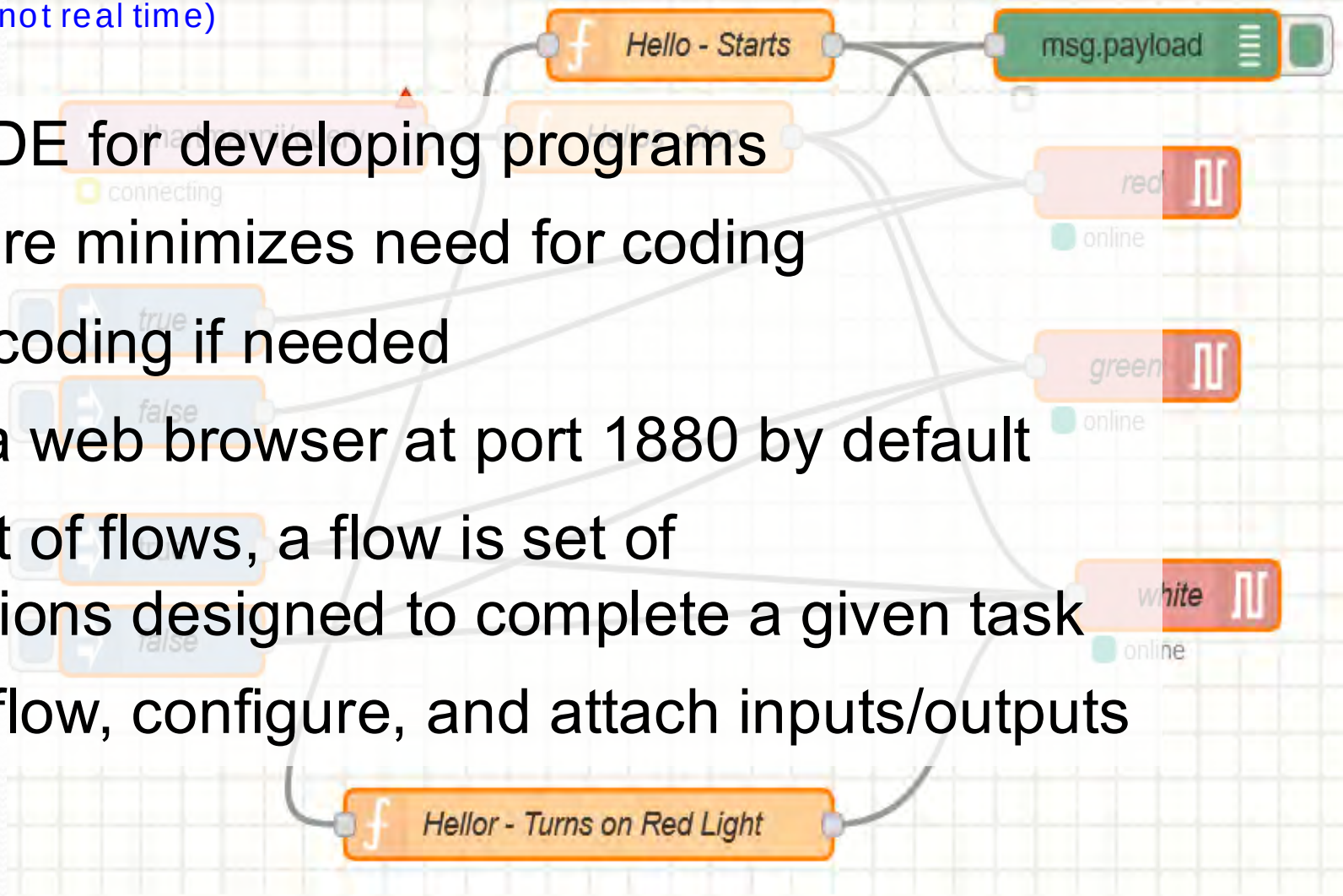




Remember, there is no programming knowledge required for this class

Node-Red (not real time)

- ~5th generation IDE for developing programs
- Graphical in nature minimizes need for coding
- Allows low-level coding if needed
- Access through a web browser at port 1880 by default
- Uses the concept of flows, a flow is set of instructions/functions designed to complete a given task
- Drag nodes into flow, configure, and attach inputs/outputs

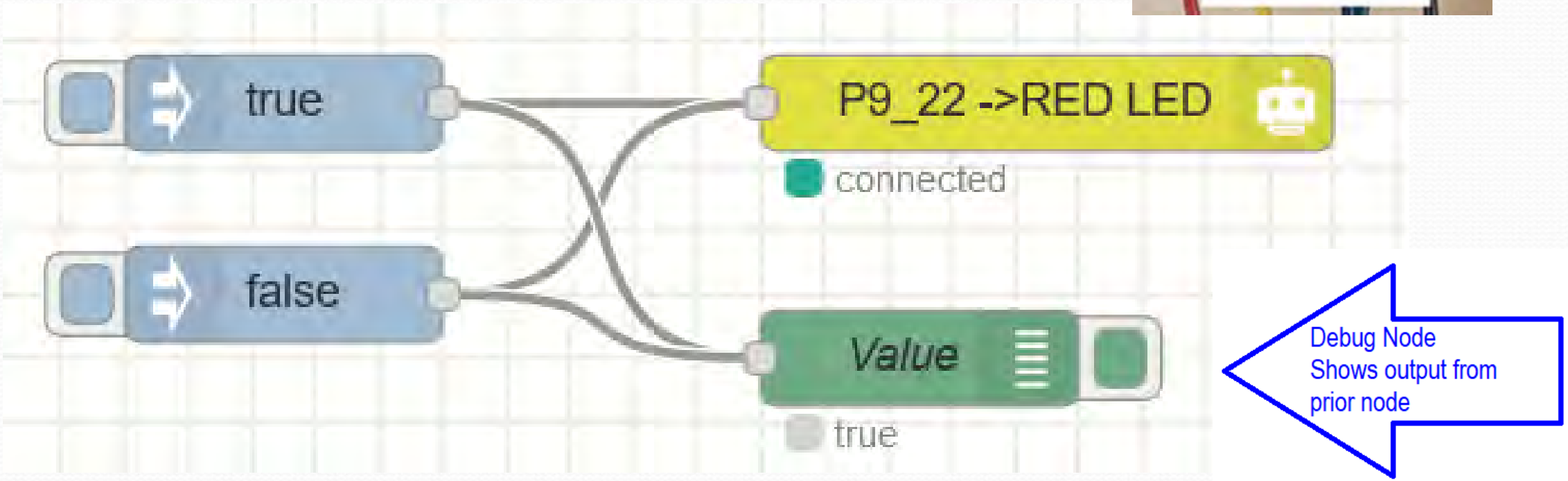


Hands on Labs

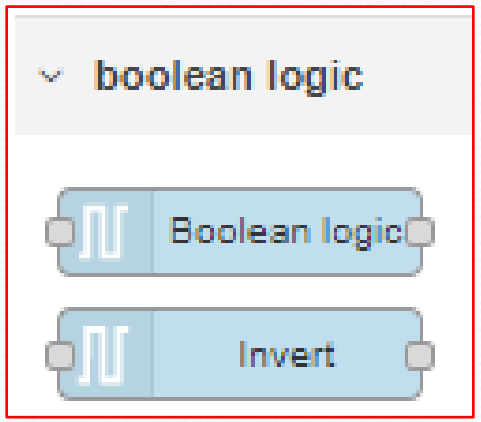
Binary Lab (2nd lab)

- Has two states

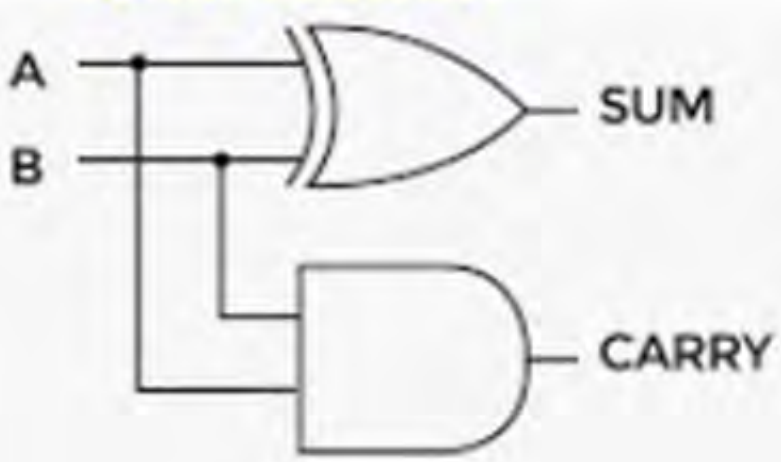
Binary Hands On

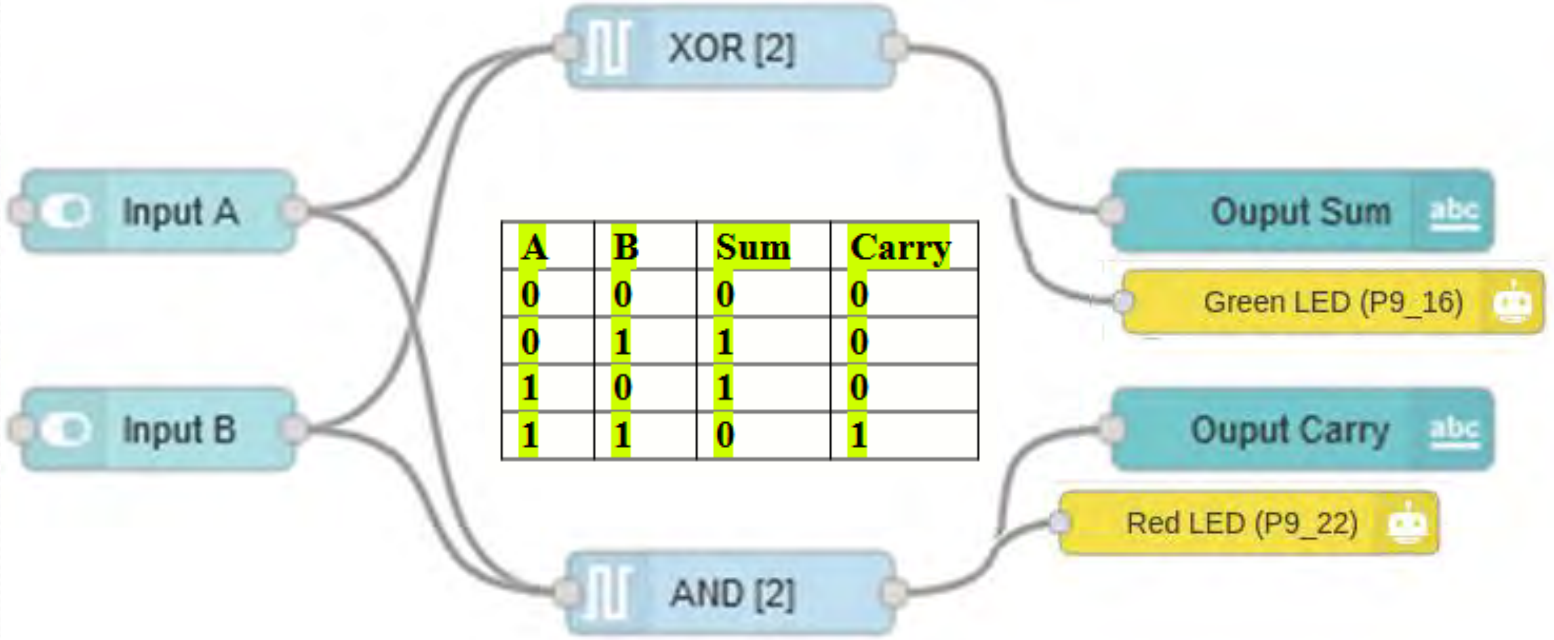


Binary Logic



Half Adder

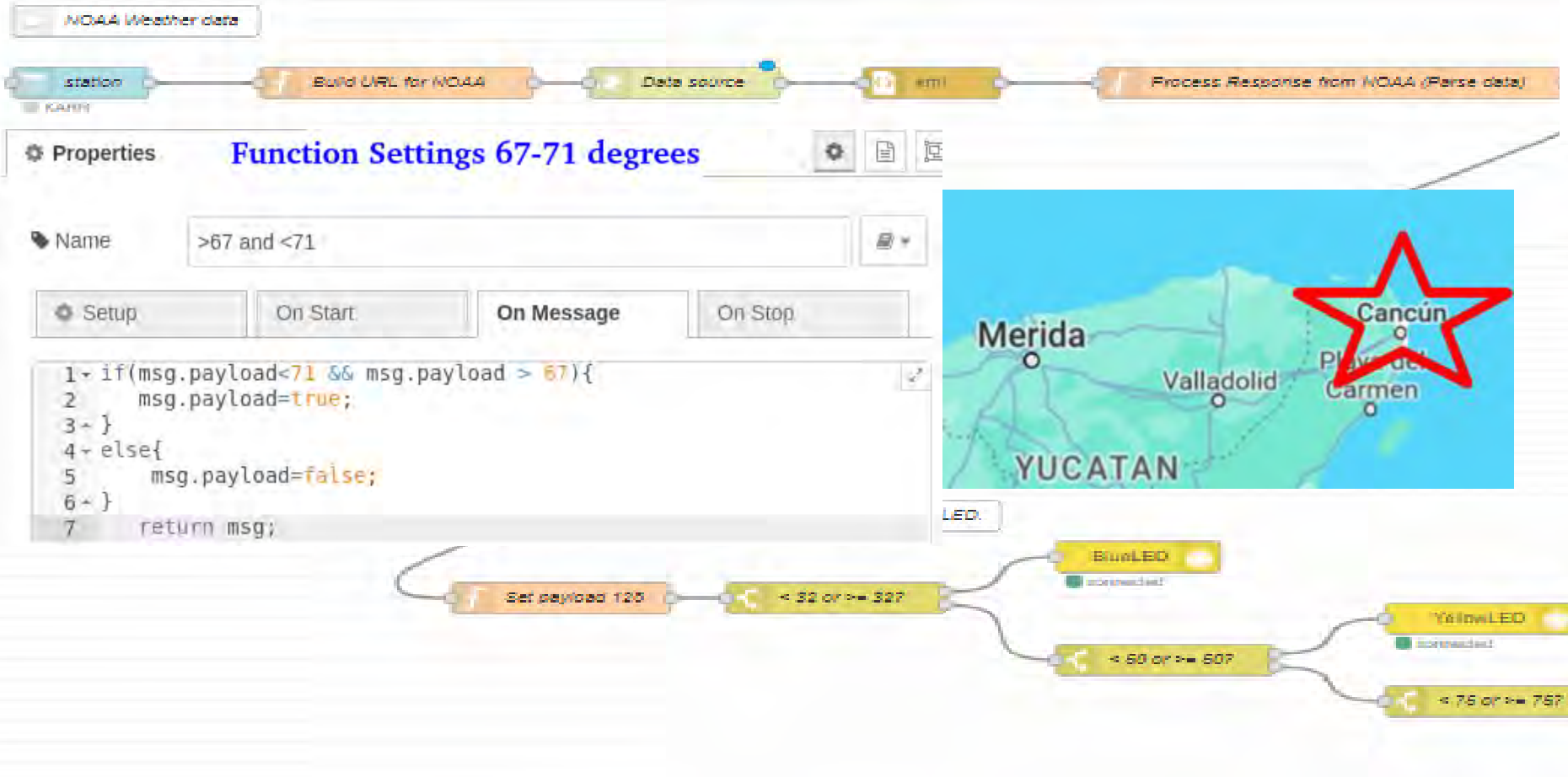




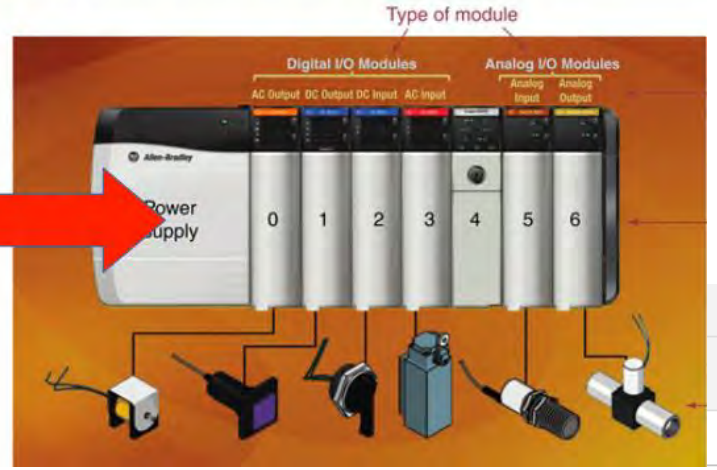
A	B	Sum	Carry
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

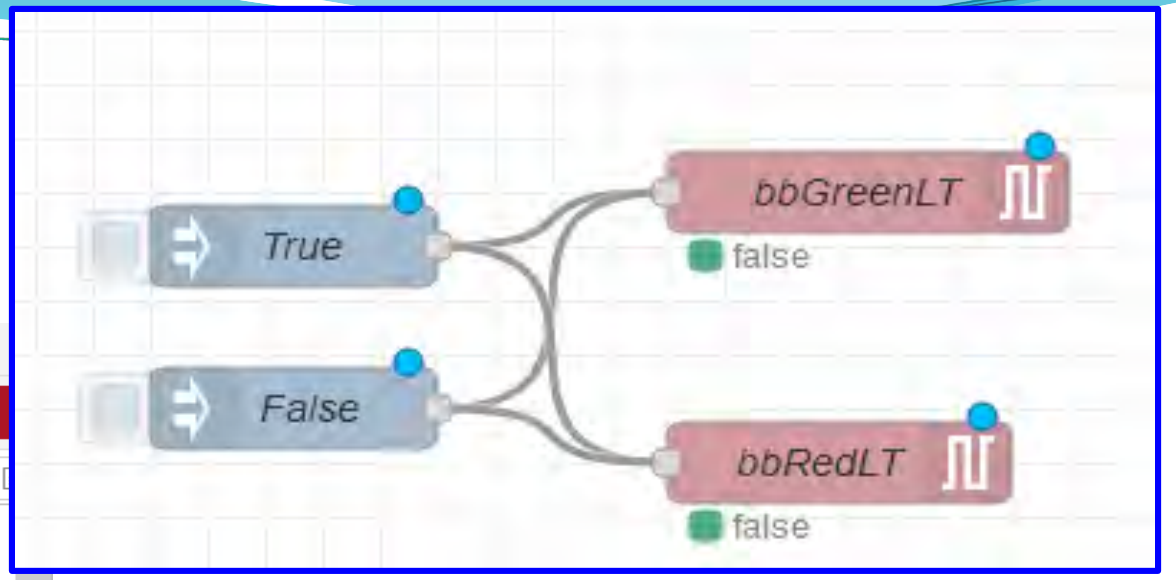
Using Node-Red to display temperatures from NOAA around the world and light LEDs

First Lab



Ethernet/IP Beaglebone to PLC





Update

Connection | Tags

IP Address: 10.101.201.158

Cycle time: 500 ms

Name: PLC154

Tag list

<Global>

Local:1:I:Data.0	BOOL
Local:1:I:Data.1	BOOL
Local:1:I:Data.2	BOOL
Local:1:I:Data.3	BOOL
Local:3:O.Data.0	BOOL
Local:3:O.Data.1	BOOL
Local:3:O.Data.2	BOOL
Local:3:O.Data.3	BOOL
Tag	

Import Export

Edit eth-ip out node

Delete Cancel Done

Properties

PLC: PLC154

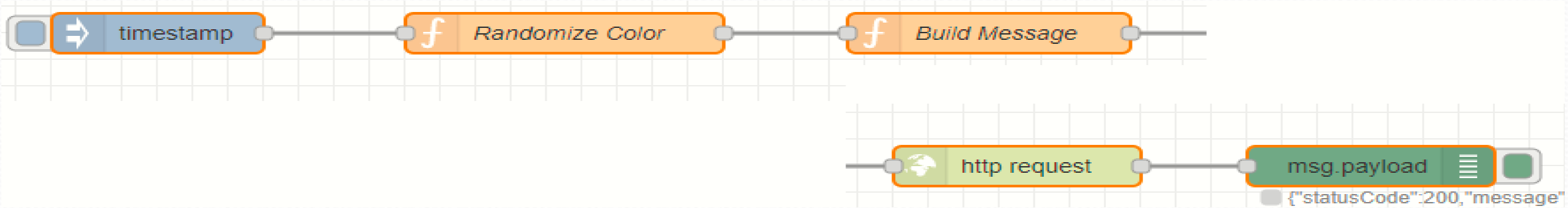
Scope: <Global>

Tag: Local:3:O.Data.0

Name: bbRedLT

Caution when writing data to production PLCs!

Cloud Services / Mingo



mingo

Production Run | Administration | History | Analytics

4/26/2022	Noon Class	Sharon's Beaglebone Machine	redCount Red Marble	View	Scrap	Running
4/26/2022	Noon Class	Machine Classroom 003	blueCount Blue Marble	View	Scrap	Running
4/26/2022	Noon Class	Hartmann prototype beaglebone -001	greenCount Green Marble	View	Scrap	Stopped

Cloud Communications

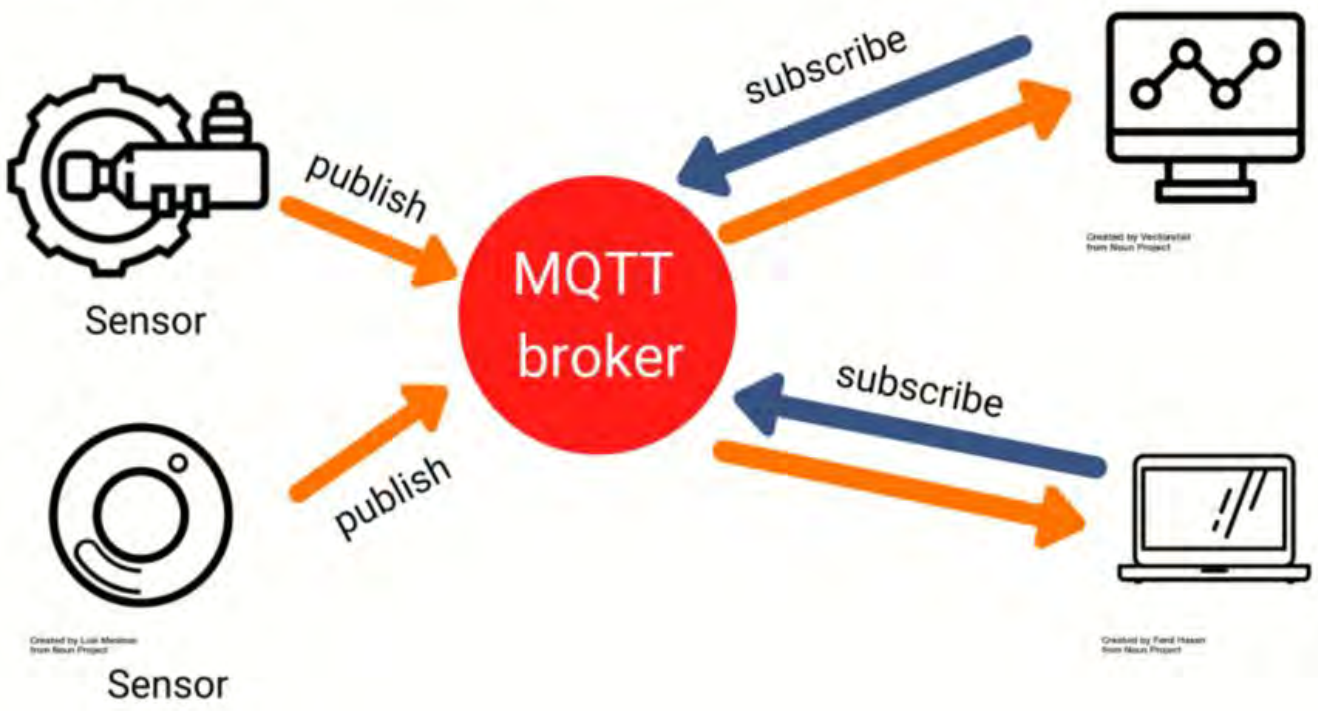
MQTT Broker

No Hole in the Firewall
No Special Permisison
Communicate from anywhere

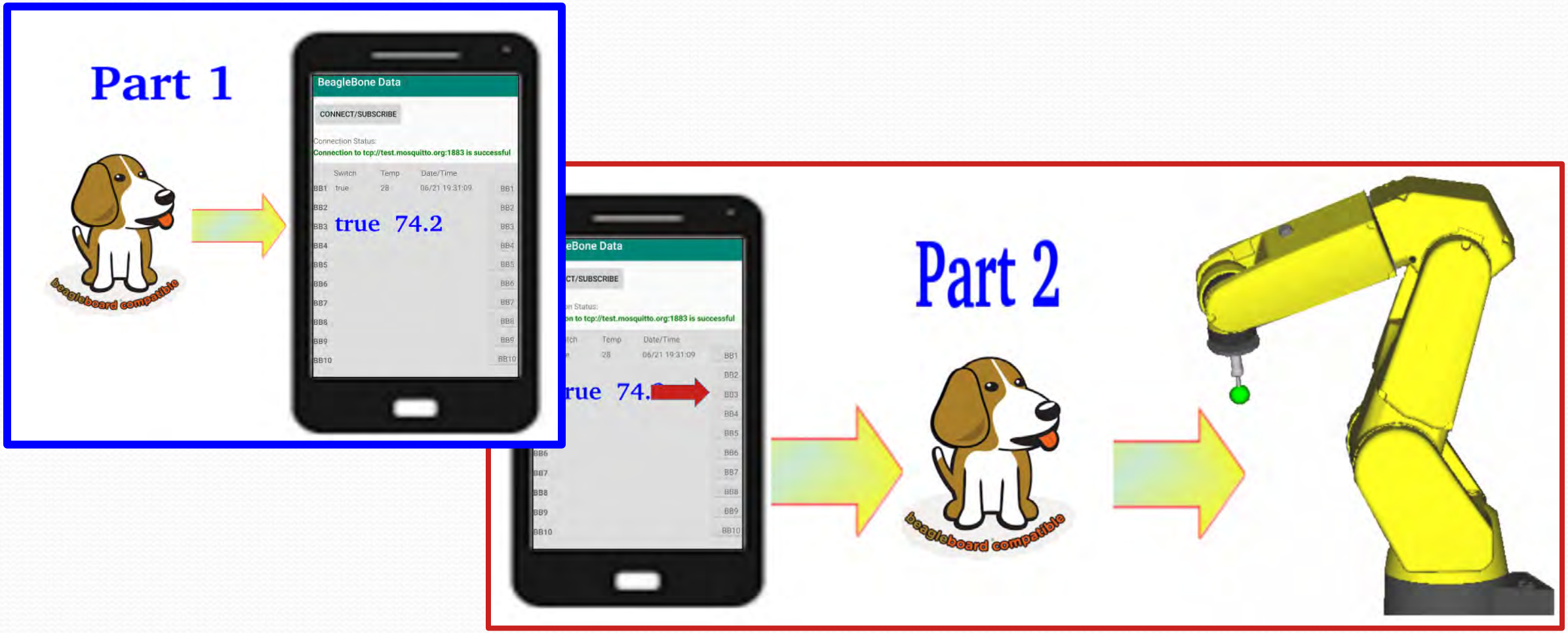
MQTT uses a publish/subscribe technique

- MQTT uses topics
  - Topics are hierarchical structures similar to the filesystem on a PC

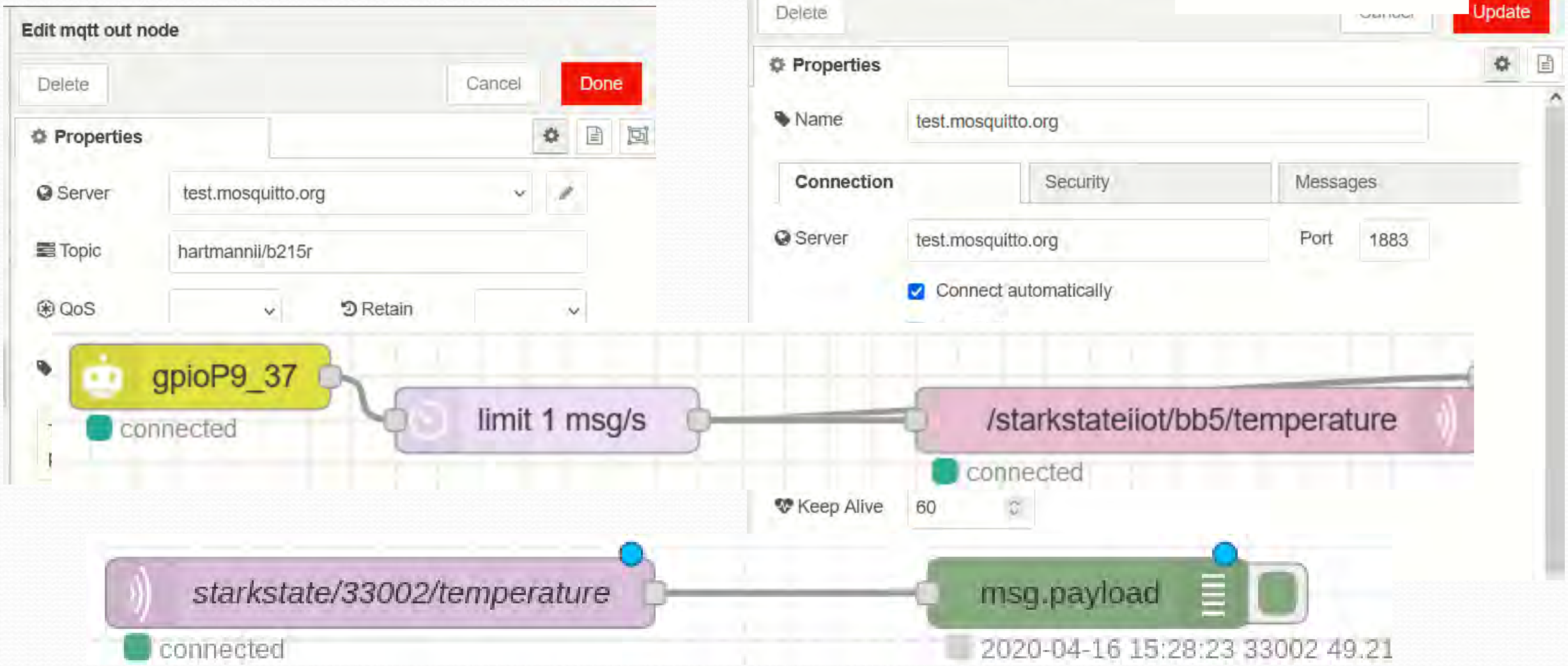
image source: https://cedalo.com/wp-content/uploads/2021/01/MQTT-Broker-1-2.png



MQTT Lab


Part 1
BeagleBone Data
CONNECT/SUBSCRIBE
Connection Status:
Connection to tcp://test.mosquitto.org:1883 is successful
Switch
Temp
Date/Time
true
28
06/21 19:31:09
true 74.2
Part 2
beagleboard compatible

Hands-on

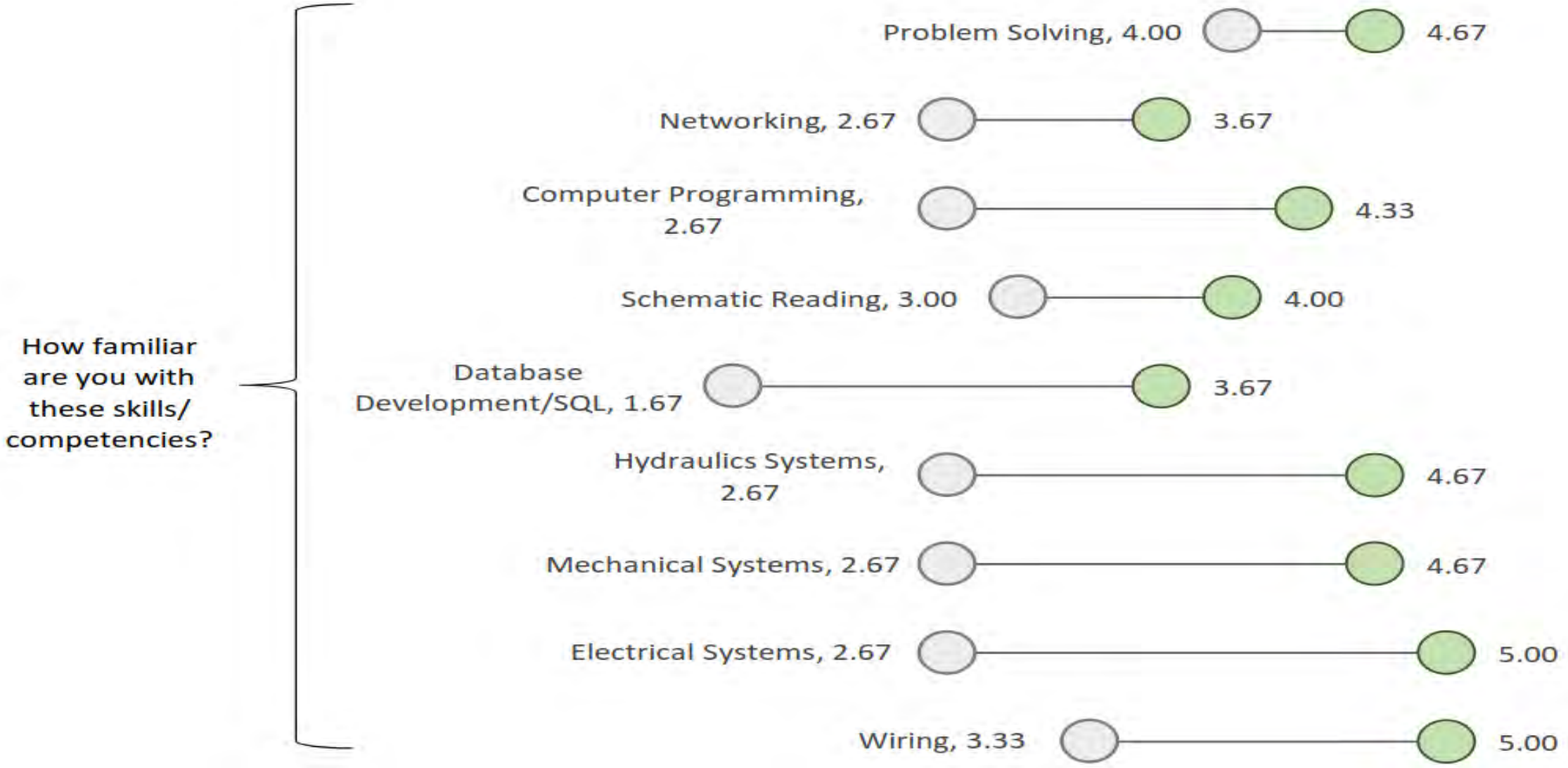

mqtt in
mqtt out
Edit mqtt out node
Delete
Cancel
Done
Properties
Server
test.mosquitto.org
Topic
hartmannii/b215r
QoS
Retain
Edit mqtt out node > Edit mqtt-broker node
Delete
Update
Properties
Name
test.mosquitto.org
Connection
Security
Messages
Server
test.mosquitto.org
Port
1883
Connect automatically
gpioP9_37
connected
limit 1 msg/s
/starkstateiiot/bb5/temperature
connected
Keep Alive
60
starkstate/33002/temperature
connected
msg.payload
2020-04-16 15:28:23 33002 49.21

Success Stories

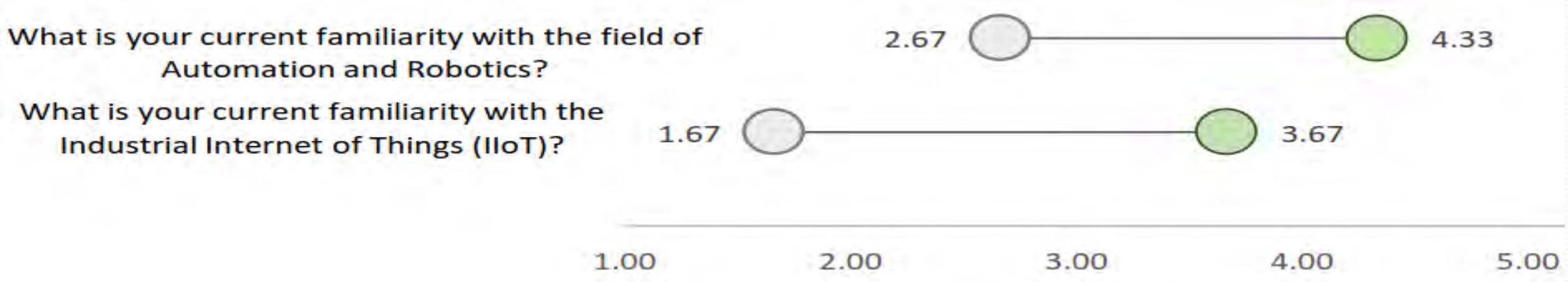
Several students that have taken this class have reported back that they have implemented some of the technologies at work

Because this trainer is so lost cost, I have had two students take the class online. The were able to purchase the parts necessary and I was able to assist them via zoom

Survey Responses from IIoT Class



Survey Responses from IIoT Class (Cont.)



Activities

Workshop – East Akron HS

Activities

Workshop – Glenn Oak

Questions ?

Contact Information:

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Automation and Robotics

Stark State College

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Automation and Robots Link:
https://www.starkstate.edu/academics/programs/automation-and-robotics-technology/

Automation and Robotics Programs at Stark State

- Offerings must be *Stackable*
- Short term certificates of 12-16 credits
- One-year Certificate Automation and Robotics Technology
  - max 30-32 credits
- Two year Associate of Applied Science (AAS) program Automation and Robotics Technology
  - max 60-63 credits

State Requirements for AAS Programs

- AAS - max 60 to 65 credits
- Technical Requirements
  - 30+ Credits
- Non Technical
  - 30+ Credits
  - General Ed classes
  - Basic/related classes

Ohio's Learn to Earn Pathways

- High school students
  - Earn college credit
  - Earn high school credit
  - Obtain industry credentials
    - Must include 12 points worth of industry credentials

IIoT

Learn to Earn Pathway

- Four college classes
  - NEW CLASS Industrial Internet of Things (IIoT)
  - Introduction to Robotics
  - Industrial Robotics
    - 6 point credential (HandlingTool…)
  - Introduction to Networking
    - 6 point credential Network+

What is Real-Time Control?

- **Real-time** implies that information is received as the events are happening. This concept of real-time has several facets
  - **Hard real-time** – information is being received within a guaranteed time so that as events occur, the controller is sure to receive this event in time to make necessary decisions to ensure proper production, safety, etc. is maintained
  - **Soft real-time** – Data is being received regularly that is keeping supervisors, management, interested parties up to date on the progress. If some data is delayed or lost no harm is done

Real-time Control

Real-time Control is needed to ensure that pumps, *etc*. are turned on/off on time

Common operating systems found on PCs, laptops, and even smartphones are not real-time devices

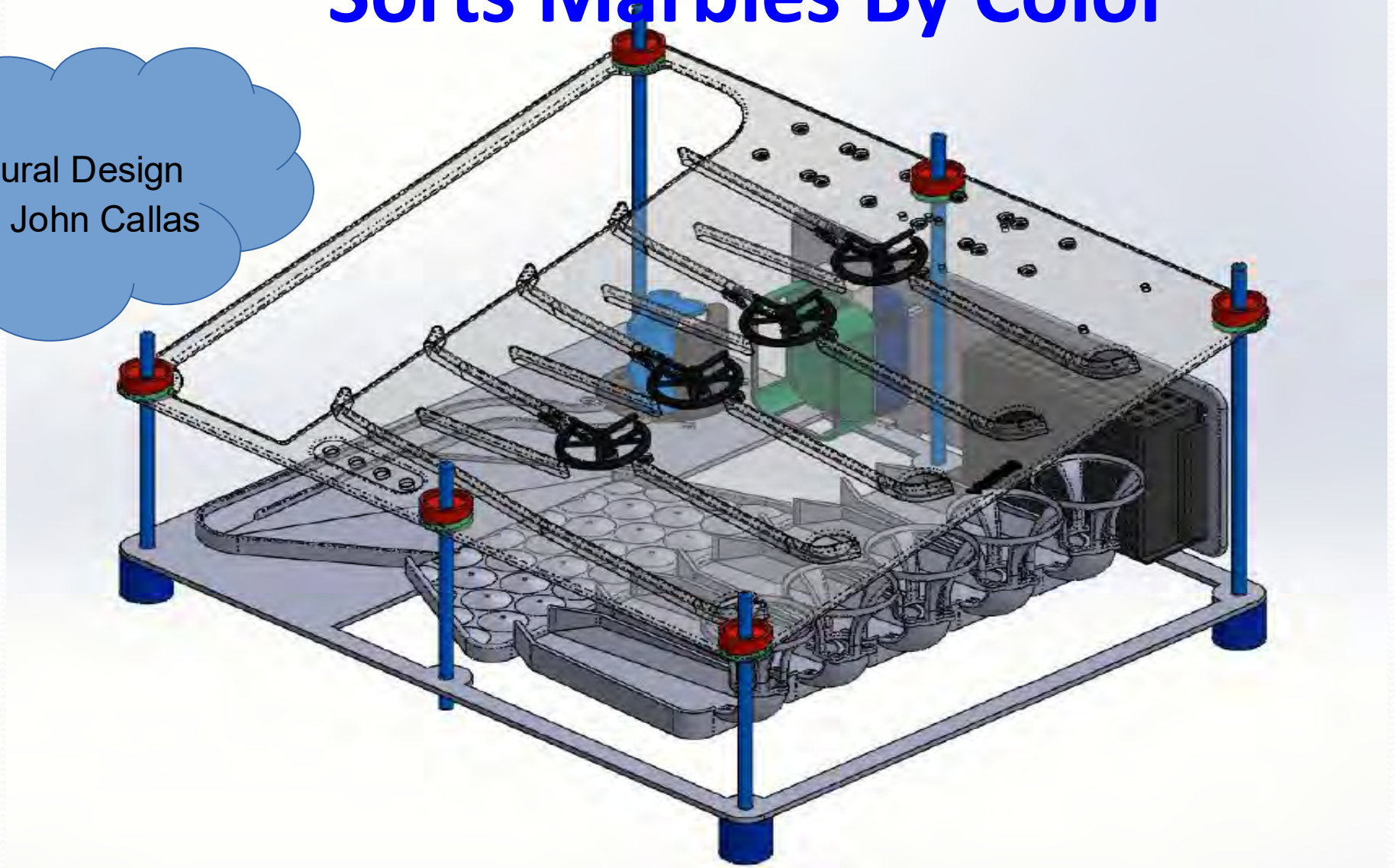
Features of
Marble Machine IIoT Trainer

- Fun
- Very Small foot print
- Low cost
- Print parts using 3D printers
- Expandable / Connect multiple trainers
- Count marbles different types of sensors
- Detect types of marbles
  - Metal or glass
  - Based on color
- Monitor speed of marbles and motors
- Control speeds
- Implement networking/ cloud communications
- Interface with FANUC robots and PLCs

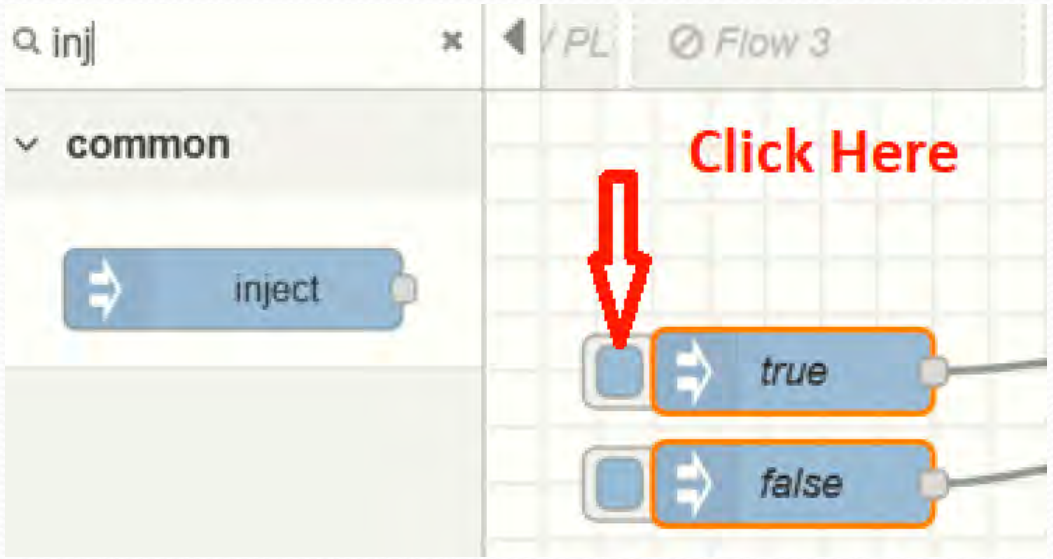
https://www.youtube.com/watch?v=JlLFpG7yahk

Marble Machine Trainer
Sorts Marbles By Color

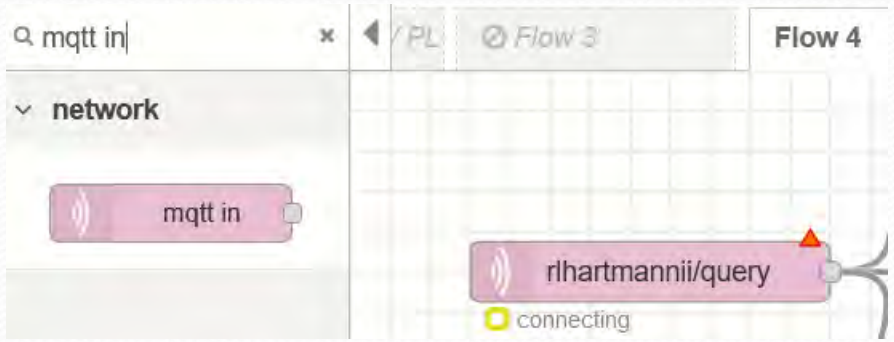
Structural Design
by Prof. John Callas



Inputs



Inject: User input or repeat
Click on square at left to inject

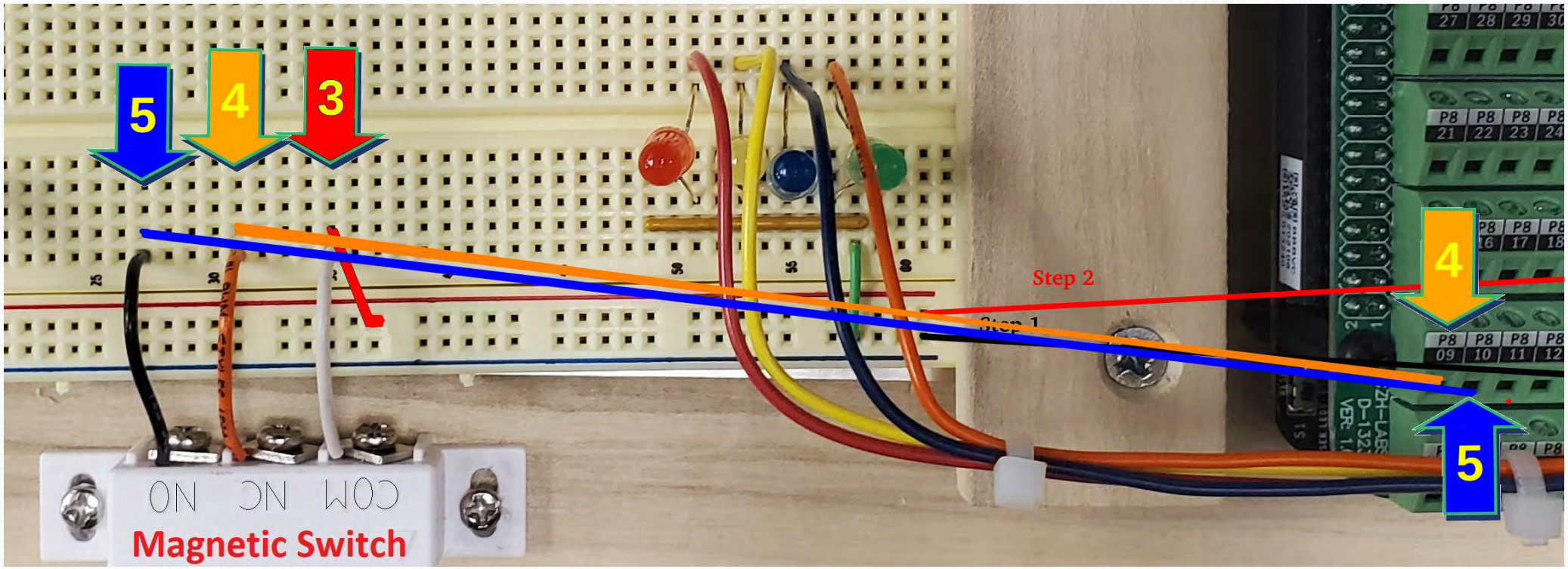


Network input
Read from next input into flow

Physical input
Read input from controller

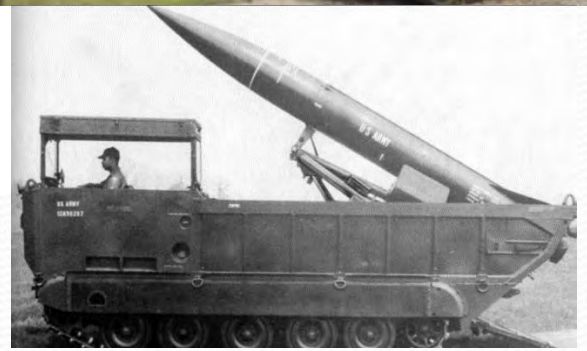
Magnetic Switch

- Read in Switch value and display state using LED



My Background

- U.S. Army: Fire direction control Repair
- BS, MS, Ph.D. from Akron
  - Specializing in automation and controls
- Setpoint calculator design at Goodyear
- Automation for U.S. Court systems
- Stark State College for 20+ years
- Consulting



Node-Red Analog Output

- **Digital Output**
  - Outputs a 1 or 0, high/low
- The **Analog output** option of the Node-red interface actually outputs a PWM signal
  - 64 – 25% duty cycle
  - 128 – 50% duty cycle
  - 255 – 100% duty cycle
- **Servo Output** Outputs PWM, but takes values 1-80 as degrees for the servo

Outline

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- IIoT Course
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- Outcomes