Grab an attendance sheet

6.900

Lecture 3

February 11, 2025

This week

- EX02
  - Peer review of sensor board schematics – **due this Thu!**
  - Sensor board layout
  - Buck converter schematic design
  - Plotly
  - A few other exercises
- Lab 2
  - Teams formed – now get going!
  - Lots to do!

It’s a busy week!

Some thoughts on week 1

This class has lots of moving parts: HW, FW, SW, server, etc.

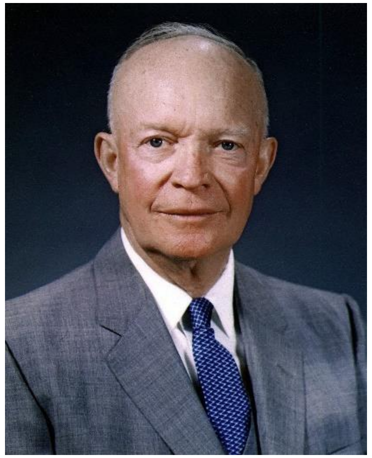
Some issues can take a while to debug

Don’t wait until the last minute to get started on stuff

TODAY

- The HW/SW product development process *with a focus on engineering design*
- And some team stuff in there
- And then Joe will talk about PCB layout

"In preparing for battle I have always found that plans are useless, but planning is indispensable"
--Dwight D. Eisenhower



MITOS Campus Heat Monitor

1. It should accurately measure the air temperature and humidity, with dynamics appropriate for the use case.***
2. It should measure ground surface temperature, with dynamics appropriate for the use case.*
3. It should operate without being connected to line voltage.***
4. It should be portable and able to be set up by an average person in a variety of outdoor environments on the MIT campus, including on a tripod or attached to poles of various dimensions.***
5. It should be able to be physically attached to a HOBO MX2302A data logger.*
6. It should report faults, such as battery failure, falling, vandalism, etc.**
7. It should be as inexpensive as possible.***
8. Data from a sensor node should be able to be tied to a location.***
9. It should maintain privacy.***
10. It should operate independently without user intervention for 3+ months.***
11. It should be rugged and able to withstand a summertime Boston-area environment (heat, rain, wind and curious people).***
12. Multiple systems should be able to be used simultaneously.***
13. It should engage with the community.**
14. The system should present the information on a dashboard (with real-time data outputs to a dashboard if possible), and also allow downloading of raw data.***

* → ***: level of importance

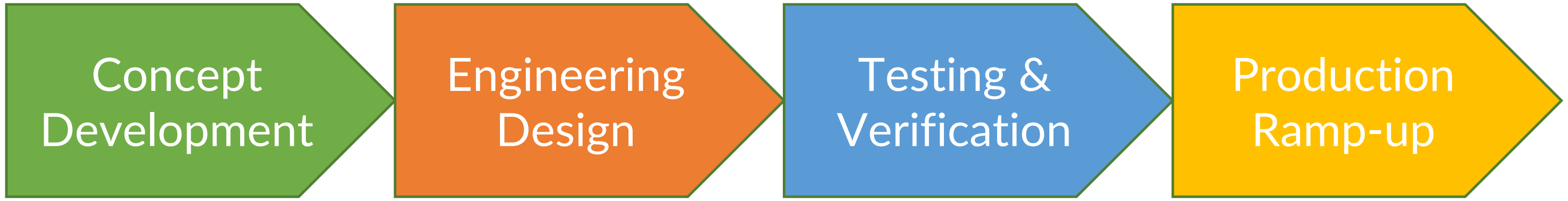
City of Cambridge Bike Lane Monitor

1. It should measure bicycle volume (number and direction, velocity is less critical) across a variety of Cambridge separated bike paths.***
2. It should operate without being connected to line voltage.***
3. It should be installable by a technician, and should be easy to set up without requiring alteration to the roadway.***
4. It should report faults, such as battery failure, falling, vandalism, etc.**
5. It should be as inexpensive as possible, with no or minimal on-going cost.**
6. It should operate ideally at all times, though if you really want to sleep, you could do so 1am to 6am.***
7. It should communicate data wirelessly, ideally in real time.**
8. Data from a sensor node should be able to be tied to a location.***
9. It should not identify individuals.***
10. It should operate independently without user intervention or servicing for at least one year.**
11. It should be rugged and able to withstand operation across typical Cambridge weather.***
12. Multiple systems should be able to be used simultaneously.***
13. The system should present information to the end-user in a useful way.*

* → ***: level of importance

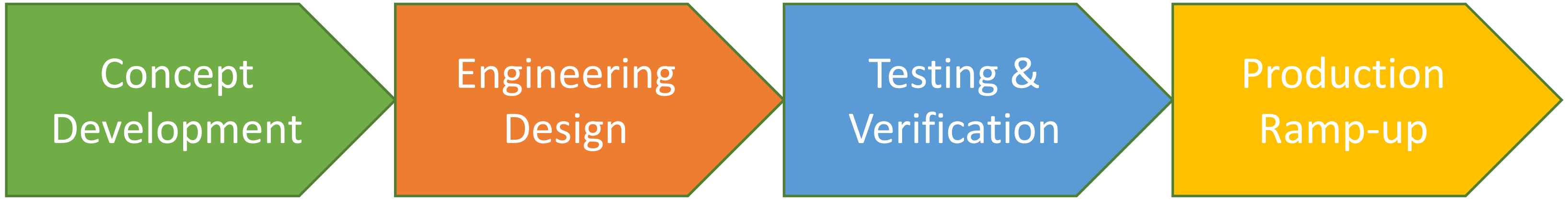
Product development process

- Many different specific processes, terminology, number of steps, and so on, but generally



- **Concept development:** identify requirements, establish target specifications, generate concepts, refine and select most promising concept
- **Engineering design:** develop product's system-level architecture, partition into subsystems, design subsystems, prototype subsystems, integrate back into system
- **Testing & verification:** Evaluate the subsystems and complete system, verifying that it meets spec
- **Production ramp-up:** Transfer to manufacturing, verify quality, ramp up production, commercialization

Concept development



- Concept development: identify requirements, establish target specifications, generate concepts, prototyping (as needed), refine and select most promising concept
- Requirements [needs]
  - Focus on **what** the system should do, rather than **how** to do it
- Identify requirements: who's requirements? ➔ stakeholders' requirements
- Stakeholders: the people affected by your product
  - Customer, end-user 🡐 these often most important
  - But also retailer, employee, installer, etc.

Stakeholders

Customers are not always end-users…

ICU monitor

Hospital procurement

Customer

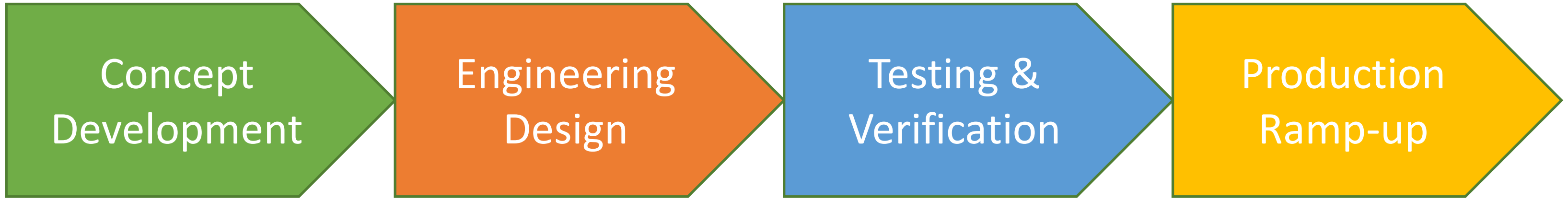
End-user

Stakeholder

Stakeholders

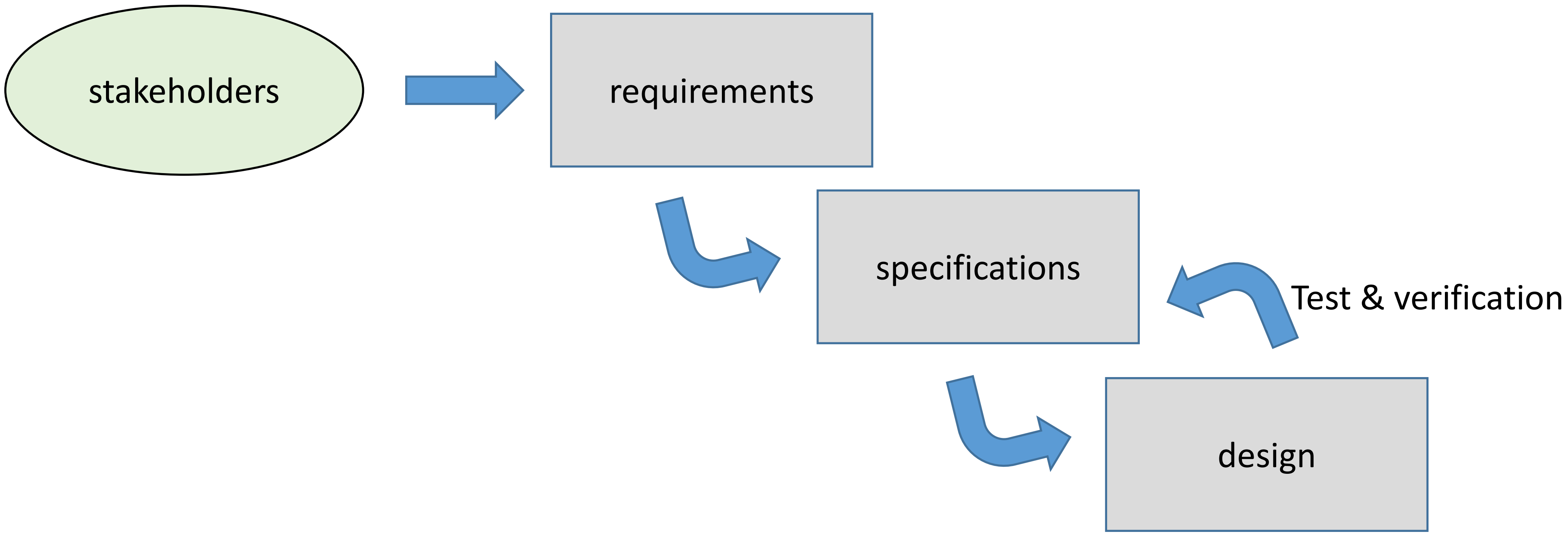
- Who are the stakeholders for our semester projects?

Now what?



- We iterate between settings specs, developing concepts, prototyping, doing design, and developing a testing plan
- Not everything will necessarily be defined yet (and thus able to be concretely specified)
  - This may not be ok for some products (aerospace, medical) but often the case for consumer, etc. ➔ Iteration can be important

Requirements, specs, and so on



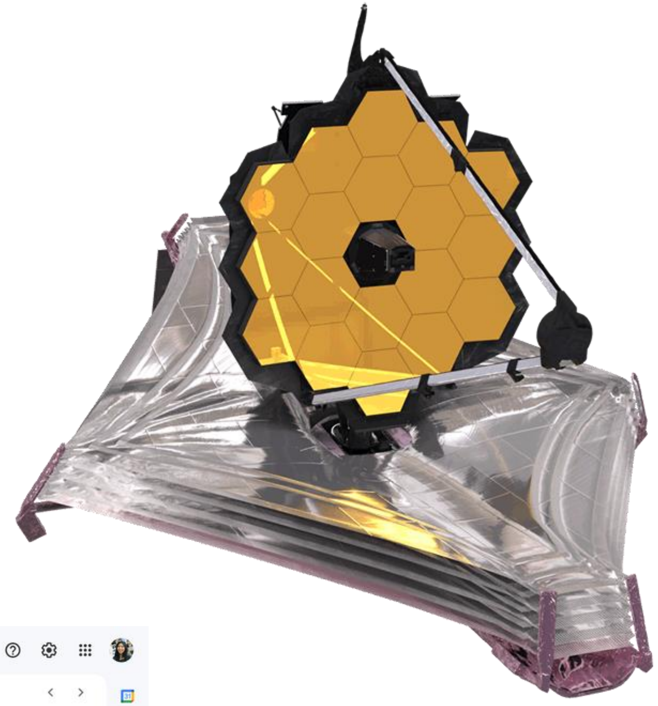
Done well, a design that passes all the tests will meet the specifications and thus the requirements, making the stakeholders happy

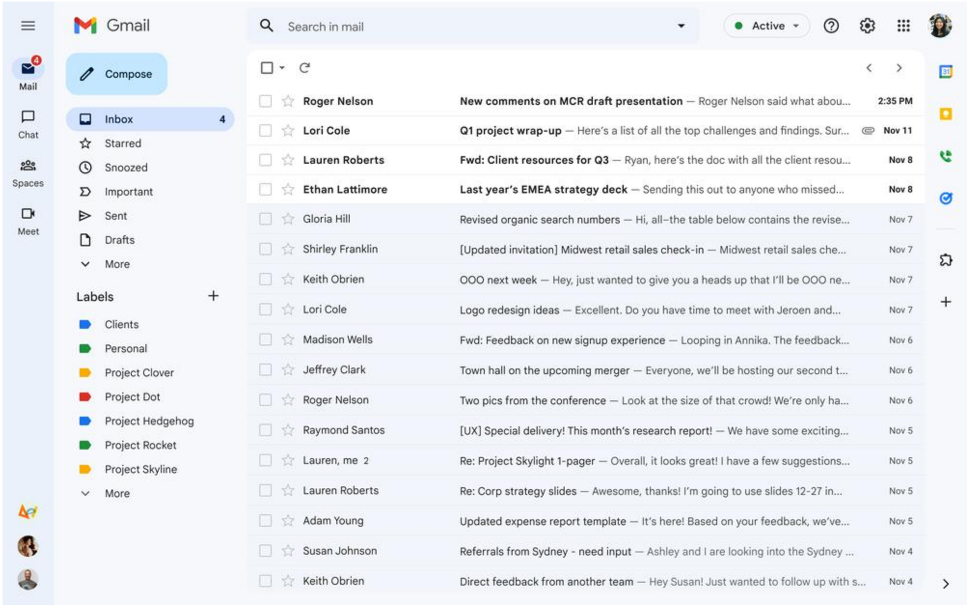
Specifications

- Translate requirements into a specification document
  - Covers both HW and SW aspects
  - The goal is to have constraints for our system→ *engineering is design under constraints*
  - If our specs are complete, and if we build something that meets spec, then it will meet our requirements
  - Some specifications will directly imply a specific approach
    - The need for interoperability with another product (that has WiFi) may immediately specify WiFi
    - The company may impose use of MySQL dB or STM32 MCU because that's what's used by the rest of the company
  - Sometimes specifications will be much more open-ended
    - An opportunity for creativity & innovation!

Specifications

- What aspects do we need to specify?
  - There is no all-encompassing approach
  - These products are all specified differently





Common specifications for HW/SW products

- Financial
  - BOM, COGS, etc.
  - Time to market
- Regulatory – safety, emissions
  - Anything with a radio, plugged into wall, etc.
  - For medical (and other regulated sectors) this can be quite extensive
- Industrial design
  - What does it look like, what materials are used, how does it interact with the user, etc.
- Environmental resistance
  - Is it used indoors? In salt water? In an auto engine? On Mars?
  - IP [Ingress Protection] rating
- Engineering
  - Sensing, actuation, compute, comms, firmware, software, etc.
- Security & Privacy
  - Typically, user data is being communicated…what data? how is it being secured? who has access?
  - There may be regulatory requirements here as well: HIPAA
- Packaging
  - How is sent to the customer, could be simple/elaborate
- Installation and servicing
  - How does one go from "in the box" to "in use"?
  - Will it be serviced in the field? Will the SW be updated? Can the HW be fixed? Warranty?

These are not disjoint:
Needing to be updated after install: is that installation or engineering?

Needing to work outdoors will impact the materials used in the industrial design

Don't worry. Just make sure it's somewhere in document

Ultimately, the specification document should encompass all requirements

Don’t get hung up if you don’t know all of the specs at the beginning

The two most important points:

1. **Have a plan:** Work hard to plan ahead…and adjust the plan as needed

2. **Write stuff down:** Your team should have a single specifications document – a common understanding

From requirements to specifications

What makes a good specification? No single approach for all of HW & SW

- It might be a well-defined metric and value (or range of values)
  - Example: BOM < = $100
  - Example: Measurement interval <= 10 min
- It could be qualitative
  - Example: HTTP GET/POST for server comms
- It could directly imply a particular implementation
  - Example: Connectivity: WiFi 802.11a/b/g/n [2.4 GHz]
- Or you might not know what it should be yet
  - Example: Sensor accuracy: ???
- Or, you might not even know about that specification
  - Example: ???

A good spec is verifiable…else how do you know if you meet the specs?

Market research

- There are (almost) always similar products out there
- They can be used to help determine specifications, feasibility, and even design

HOBO MX2302A

There are almost always existing products that you can draw from to help set specifications

Specifications

Temperature Sensor

Range	MX2301A and MX2305 internal sensors: -40 to 70°C (-40 to 158°F) MX2302A external temperature sensor: -40 to 70°C (-40 to 158°F) MX2303 and MX2304 external sensors: -40 to 100°C (-40 to 212°F), with tip and cable immersion in fresh water up to 50°C (122°F) for one year
Accuracy	±0.25°C from -40 to 0°C (±0.45 from -40 to 32°F) ±0.2°C from 0 to 70°C (±0.36 from 32 to 158°F) ±0.25°C from 70 to 100°C (±0.45 from 158 to 212°F), MX2303 and MX2304 only
Resolution	MX2301A and MX2302A: 0.02°C (0.036°F) MX2303, MX2304, and MX2305: 0.04°C (0.072°F)
Drift	<0.01°C (0.018°F) per year

Relative Humidity Sensor* (MX2301A, MX2302A only)

Range	0 to 100% RH, -40° to 70°C (-40° to 158°F); exposure to conditions below -20°C (-4°F) or above 95% RH may temporarily increase the maximum RH sensor error by an additional 1%
Accuracy	±2.5% from 10% to 90% (typical) to a maximum of ±3.5% including hysteresis at 25°C (77°F); below 10% RH and above 90% RH ±5% typical
Resolution	0.01%
Drift	<1% per year typical

HOBO MX2302A

Response Time (typical, to 90% of change)

Temperature		Without Solar Radiation Shield	With RS1/M-RSA Solar Radiation Shield	With RS3-B Solar Radiation Shield
	MX2301A internal sensor	17 minutes in air moving 1 m/sec	24 minutes in air moving 1 m/sec	NA
	MX2302A external sensor	3 minutes, 45 seconds in air moving 1 m/sec	7 minutes, 45 seconds in air moving 1 m/sec	6 minutes, 30 seconds in air moving 1 m/sec
	MX2303/MX2304 external sensors	3 minutes in air moving 1 m/sec; 20 seconds in stirred water	7 minutes in air moving 1 m/sec	4 minutes in air moving 1 m/sec
	MX2305 internal sensor	17 minutes in air moving 1 m/sec	24 minutes in air moving 1 m/sec	NA
RH		**Without Solar Radiation Shield**	**With RS1/M-RSA Solar Radiation Shield**	**With RS3-B Solar Radiation Shield**
	MX2301A internal sensor	30 seconds in air moving 1 m/sec	40 seconds in air moving 1 m/sec	NA
	MX2302A external sensor	15 seconds in air moving 1 m/sec	30 seconds in air moving 1 m/sec	30 seconds in air moving 1 m/sec

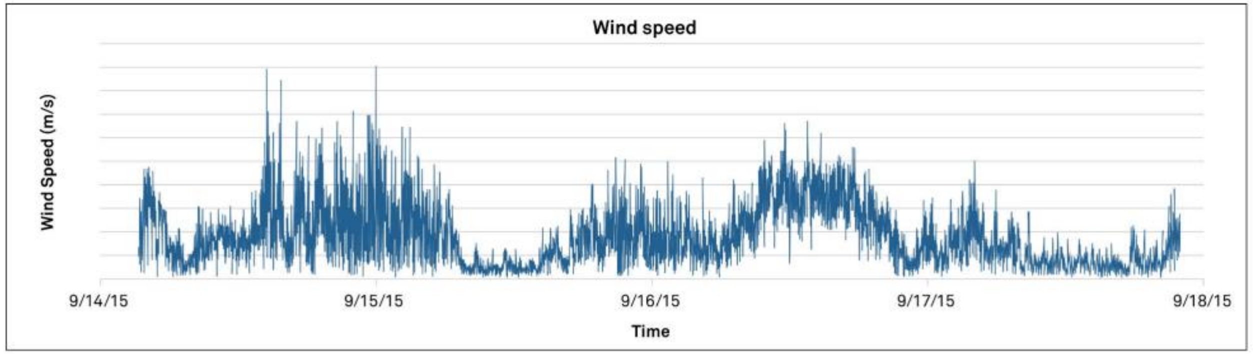
HOBO MX2302A

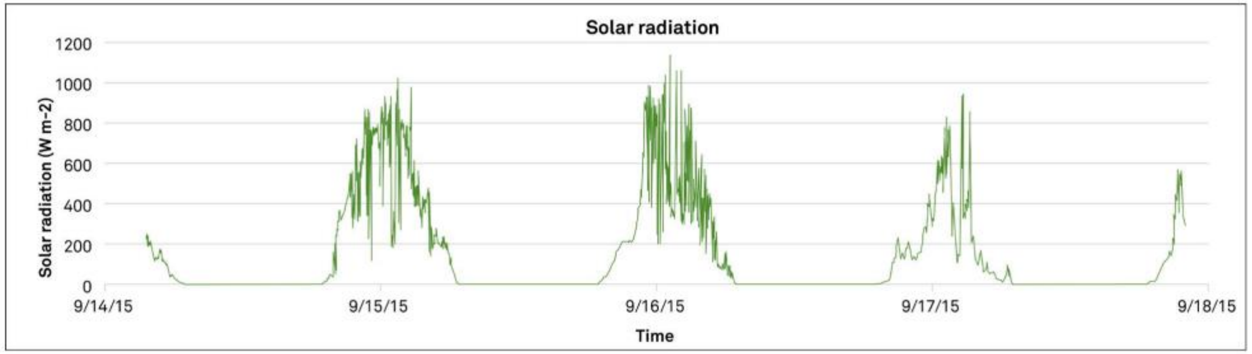
Logger

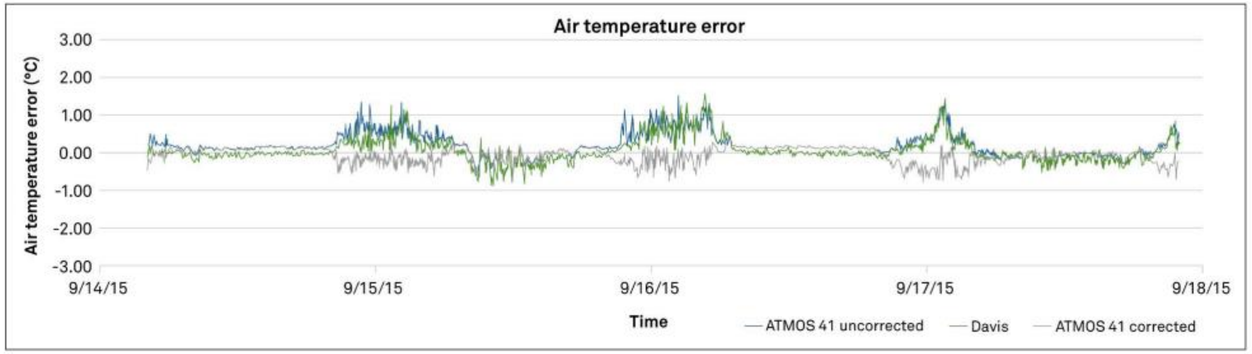
Operating Range	-40° to 70°C (-40° to 158°F)
Radio Power	1 mW (0 dBm)
Transmission Range	Approximately 30.5 m (100 ft) line-of-sight
Wireless Data Standard	Bluetooth Low Energy (Bluetooth Smart)
Logging Rate	1 second to 18 hours
Logging Modes	Fixed interval (normal, statistics) or burst
Memory Modes	Wrap when full or stop when full
Start Modes	Immediate, push button, date & time, or next interval
Stop Modes	When memory full, push button, date & time, or after a set logging period
Time Accuracy	±1 minute per month 0° to 50°C (32° to 122°F)
Battery Type	2/3 AA 3.6 Volt lithium, user replaceable
Battery Life	2 years, typical with logging interval of 1 minute and Bluetooth Always On enabled; 5 years, typical with logging interval of 1 minute and Bluetooth Always On disabled. Faster logging intervals and statistics sampling intervals, burst logging, remaining connected with the app, excessive downloads, and paging may impact battery life.
Memory	MX2301A and MX2302A: 128 KB (63,488 measurements, maximum) MX2303, MX2304, and MX2305: 128 KB (84,650 measurements, maximum)
Full Memory Download Time	Approximately 60 seconds; may take longer the further the device is from the logger
Dimensions	Logger housing: 10.8 x 5.08 x 2.24 cm (4.25 x 2.0 x 0.88 in.) External temperature sensor diameter: 0.53 cm (0.21 in.) External temperature/RH sensor diameter: 1.17 cm (0.46 in.) External sensor cable length: 2 m (6.56 ft) Solar radiation shield bracket: 10.8 x 8.3 cm (4.25 X 3.25 in.)
Weight	Logger: 75.5 g (2.66 oz) Solar radiation shield bracket: 20.4 g (0.72 oz)
Materials	Acetal, silicone gasket, stainless steel screws
Environmental Rating	NEMA 6 and IP67
CE	The CE Marking identifies this product as complying with all relevant directives in the European Union (EU).
	See last page

*Per RH sensor manufacturer data sheet

ATMOS 41W MX2302A







https://www.youtube.com/watch?v=Xf34bOmZET4
https://publications.metergroup.com/Sales%20and%20Support/METER%20Environment/Website%20Articles/atmos-41-correction-air-temperature-measurements-radiation-exposed-sensor.pdf?_gl=1*1y81m63*_gcl_au*MjExMzcyNTAwNi4xNzM5MTk3OTgz

ATMOS 41W MX2302A

Measurement Specifications	Upload Frequency	Hourly upload (default) Contact Customer Support for more frequent reporting options. Additional charges may apply.
	Measurement Interval	5 min to 12 h (average or accumulation of more frequent sensor readings) (Section 2.2.7 of *ATMOS 41W User Manual*).
	Time Keeping	Synchronize automatically and on-demand; GPS, cellular, or ZENTRA Utility software.
	Solar Radiation	**Range:** 0–1,750 W/m^2 **Resolution:** 1 W/m^2 **Accuracy:** ±5% of measurement typical
	Relative Humidity (RH)	**Range:** 0–100% RH (0.00–1.00) **Resolution:** 0.1% RH **Accuracy:** Sensor measurement accuracy is variable across a range of RH. See chart.
	Air Temperature	**Range:** –63 to 60 °C **Resolution:** 0.1 °C **Sensor Accuracy:** ±0.2 °C at 25 °C **Measurement Accuracy:** ±0.6 °C from –20 to 50 °C For more information see Section 3.2.6 of the *ATMOS 41W User Manual*
	Humidity Sensor Temperature	**Range:** –63 to 80 °C **Resolution:** 0.10 °C **Accuracy:** ±0.2 °C

ATMOS 41W MX2302A

Communication Specifications	Internet Downloads	SSL/TLS encrypted
	Cellular Communication	**3G Specifications:** UMTS 3G 5-band cellular module with 2G fallback **3G Coverage:** 550+ global partner carriers Cellular and data hosting service provided by METER **4G Specifications:** 4G LTE-M and NB-IoT cellular **4G Coverage:** VERIZON, AT&T®, and T-Mobile in the USA. Select global partner carriers Cellular and data hosting service provided by METER **NOTE: 4G is available in USA, Canada, and select other countries (Contact Customer Support or a METER sales partner for more information).**
	Mobile Communication	Bluetooth 5.2—supporting Bluetooth Low-Energy protocol.
	GPS Communication	**Type:** Integrated 56-channel GPS/QZSS receiver **Update:** Daily (automatic) and on-demand (manual) **Accuracy:** ±4 m, with good sky view

ATMOS 41W MX2302A

Physical Specifications	Dimensions	**Width:** 16.5 cm (6.5 in) **Height:** 31.8 cm (12.5 in)
	Memory Type	Nonvolatile flash, full data retention with loss of power
	Data Storage	8 MB (more than 100,000 records)
	Battery Capacity	6 AA NiMH or alkaline batteries
	Battery Life	**Alkaline:** 7 months typical for hourly uploads or 4 months with 15-min data upgrade. **NiMH:** 3+ years with an unobstructed view of the sun. Charging through solar energy harvesting.
	Operating Temperature Range	**Minimum:** –40 °C **Typical:** NA **Maximum:** 60 °C **NOTE: Barometric pressure and relative humidity sensors operate accurately at a minimum of –40 °C. Alkaline batteries should be used if temperatures below -40 °C are expected.**
Other	Compliance	EM ISO/IEC 17050:2010 (CE Mark) Prop 65 warning
	GSA	View GSA details

PERSPECTIVES IN PRACTICE

Bicycle Detection

A review of available technologies and practical experience to aid in the creation of smarter intersections that work for all users

SUMMARY

Across the United States, approximately two-thirds of reported bicycle crashes happen at intersections. Detecting the presence of people bicycling at or approaching signalized intersections and roadway crossings can offer traffic engineers additional tools and flexibility to improve the comfort and safety for this vulnerable user group. This white paper provides a deeper discussion on the various technologies that are available and provides insight on their strengths, weaknesses and practical applications.

Contributors:

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Kirk Paulson, PE, Senior Engineer
Lindsay Zefting, PE, Principal

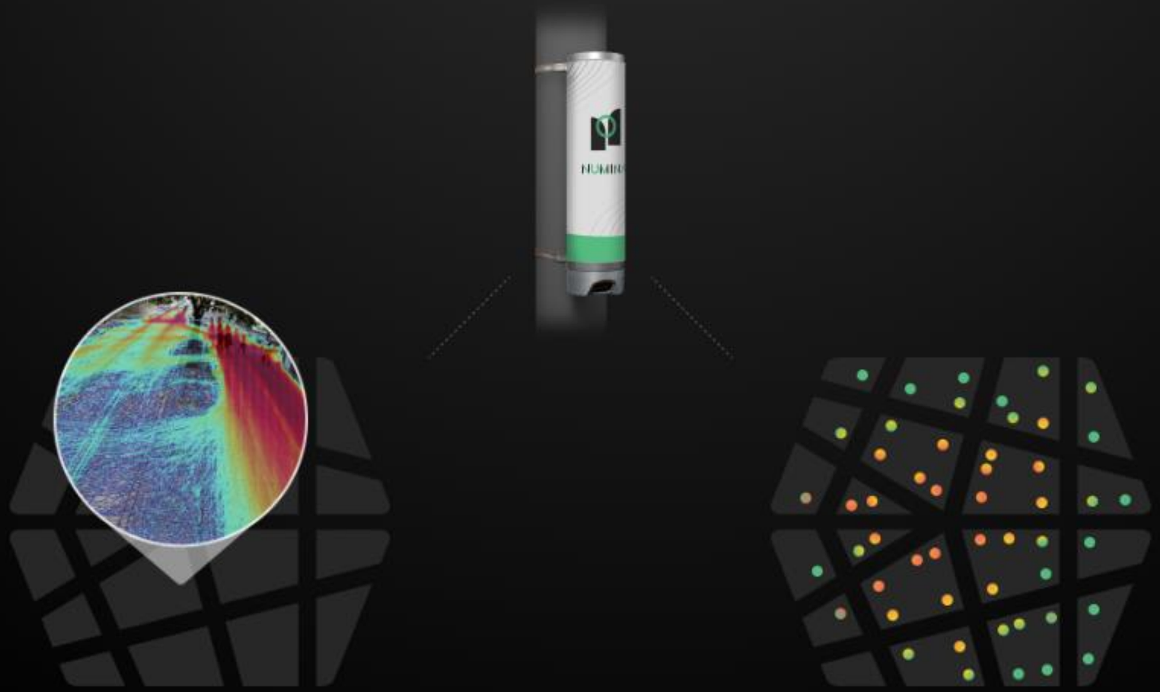
alta

https://altago.com/wp-content/uploads/ALTA_Bike_Detection_White_Paper_July2021.pdf

Unprecedented street-level data

Numina's sensor is purpose-built for streets and easy to deploy.

See how cities use Numina →



Deploy one Numina sensor

To understand granular traffic safety, environmental conditions, and operational metrics in streets.

Deploy a network of Numina sensors

To build a data utility that turns streets into a developer platform.

Our sensor is a standalone solution to street metrics

Plug-and-play

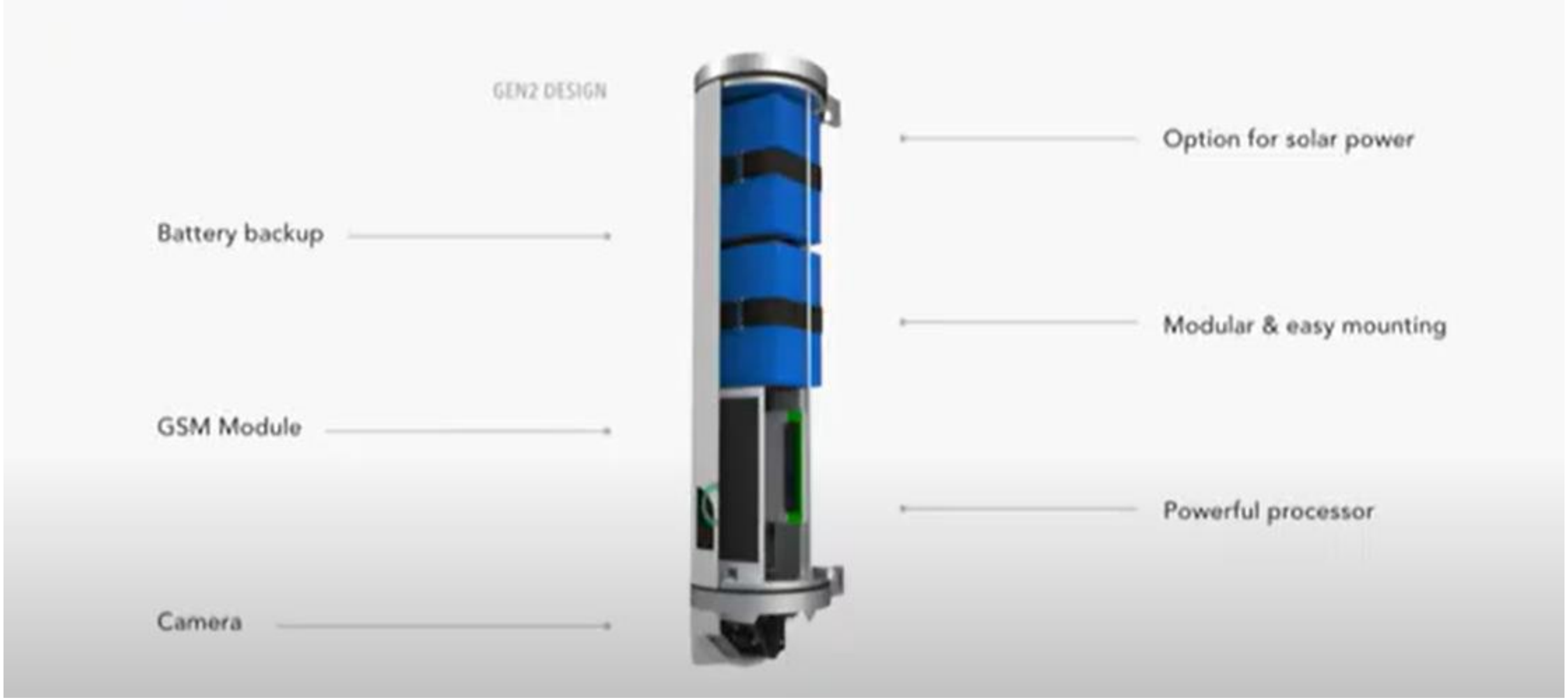
Easy to install, aim, and activate via mobile app

Deploy-anywhere

Attaches to any fixed infrastructure with standard mounting kits

Safe and secure

Gold-standard secure-by-design practices like mutual authentication and strong encryption



This talk is from 2018…

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

An update to Numina's Privacy Policy: Introducing Calibration Mode

Sarah Toulmin March 10, 2022

Today, Numina works in dozens of cities on three continents, and the demand grows as communities take more aggressive approaches to fighting climate change, recovering from the pandemic, and increasing mobility access. As we deploy ...

Read More →

Teams

- Sent out last night on Piazza
- We may adjust over the next week or so
- Teams are not competitors – develop independent designs but collaborate on key pain points

Teams

MIT Office of Sustainability Heat Monitor

Team 1: anahi183, charlesy, linnie, phaertel, rbchavez, robinl21, taboada, toyat

- *Mentor: Joel & Srinidhi*

Team 2: belacm, cchen117, dclay, gpcs, jakel238, momotoso, nerwong, rachcai, raulb456

- *Mentor: Joe & Hasan*

City of Cambridge Bike Lane Monitor

Team 3: antonio3, eadlr, fabianag, gting, lucg, menaf, nfelleke, njwiley, simdi428

- *Mentor: Kailas (w/ Joe and Joel as support)*

Team 4: aace217, elisew, jamalloy, jdubon, kengcol, maxtkc, pspann, pyaesone, durra

- *Mentor: Joe*

Team 5: akleang, akshay_a, anacamba, ceronj26, inimai, laptiev, lucasp20, rpartha, smyl362

- *Mentor: Joel*

Teams

- You will need to meet with your mentor each week for at least an hr

  …including this week
- All team members need to attend these meetings
- Starting next week, these meetings will include going over milestones and deliverables
- Our first review is Feb 26/27

Success on this project will require the team to start work right away

Teams

- Go find your team
- Introduce yourselves
- Figure out how you want to communicate
- Find an hour this week to meet with your mentor