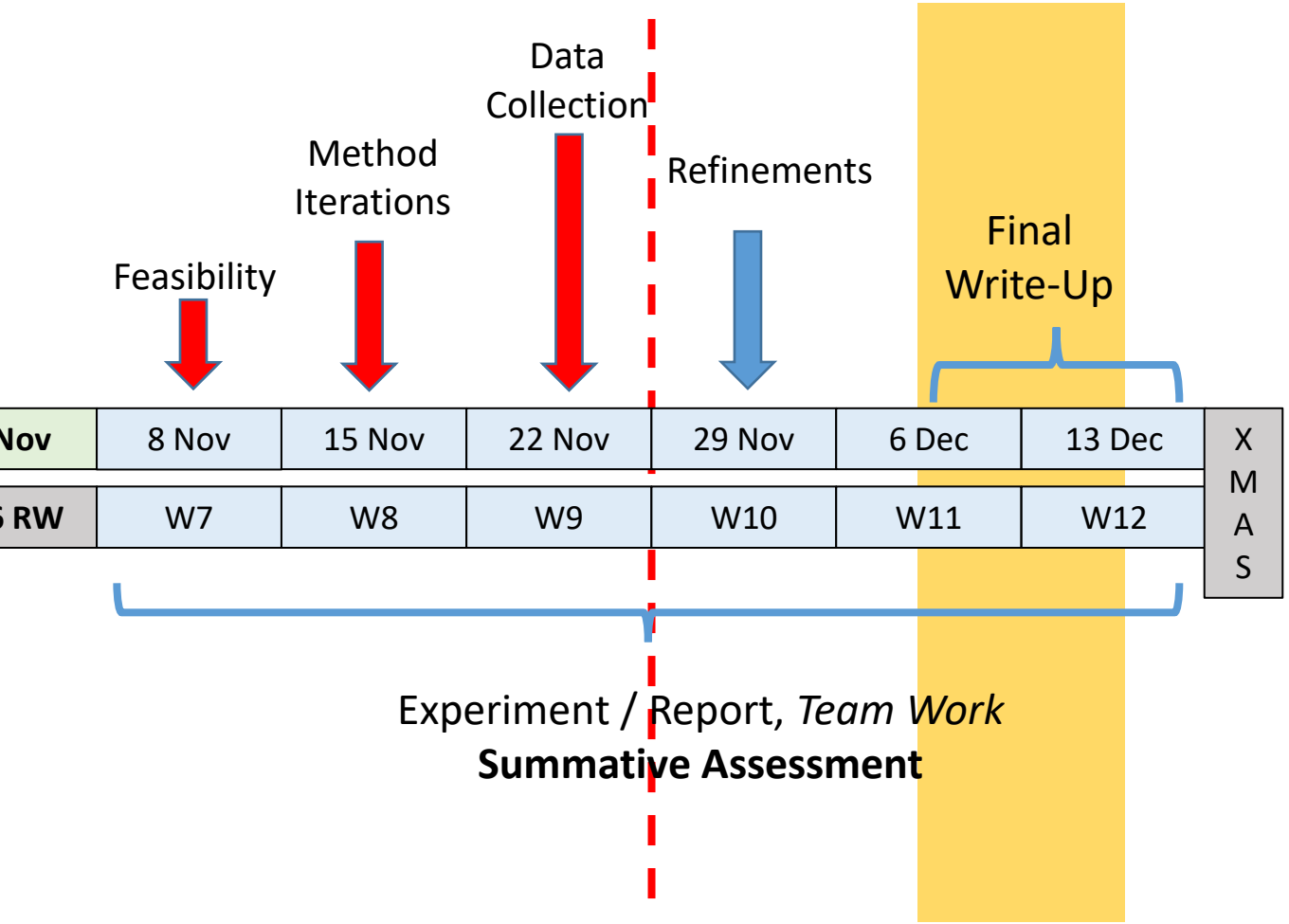
Timeline (Ideal)



Week 10-11:

- Use your draft report to hold discussion in supervision meetings

Deadline:

- Week 12
- **Wednesday 15th December 2021**
- **1pm:** Submission to Blackboard
- Report & Working code used for experiments.

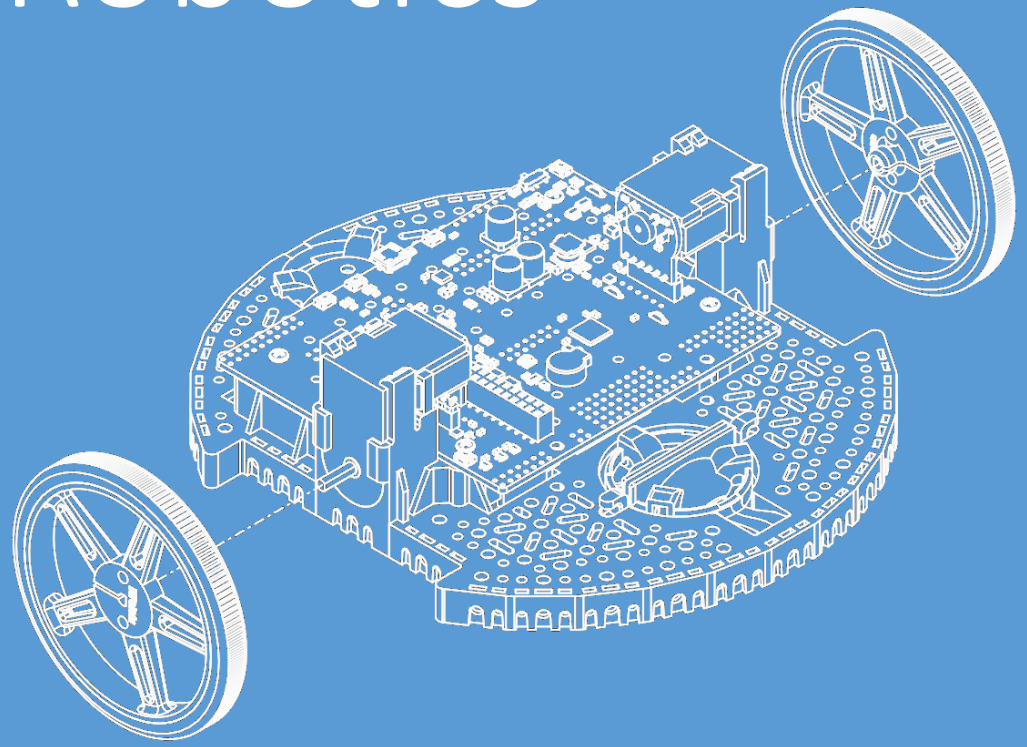
Week 12:

- No Monday Q&A
- No Supervision Meetings
- Robot Hand-In:
  - Tuesday, Queens 1.19 2pm-6pm
  - Thursday, Bill Brown Suite, 3pm-5pm

Experiments in Robotics

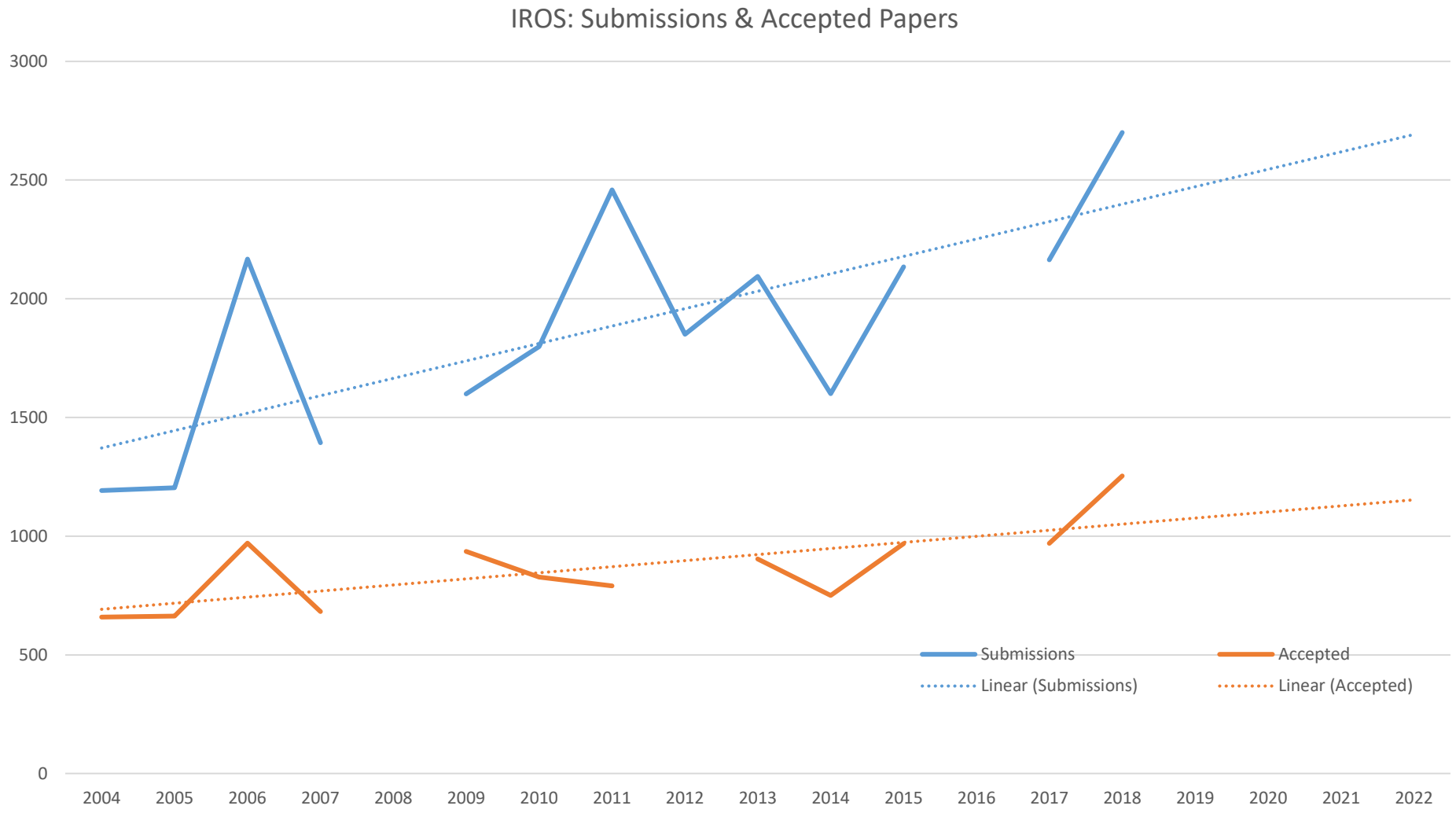
Robotic Systems

EMATM0054/53



Motivation

Motivation: International Conference on Intelligent Robots and Systems



<u>IROS:</u>
Approx. 2000 paper submissions.

30% acceptance rate.

2000 experiments in robotics, per year!

<u>ICRA 2019:</u>
2163 submissions.
44% acceptance rate.

Objective:
Communicate

Motivation: Complexity, Reproducibility

Laboratory

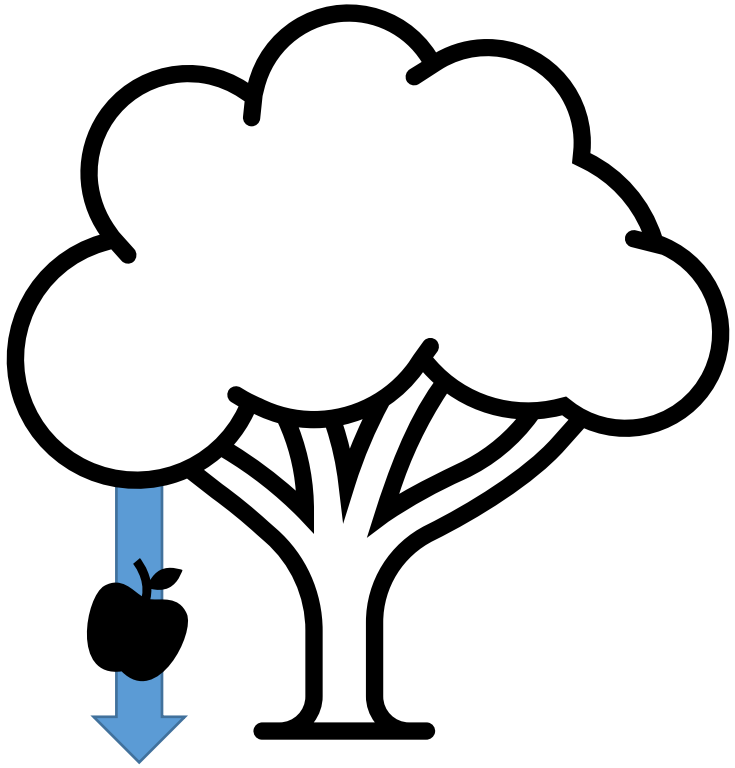
Shakey, 1966

"Real world"

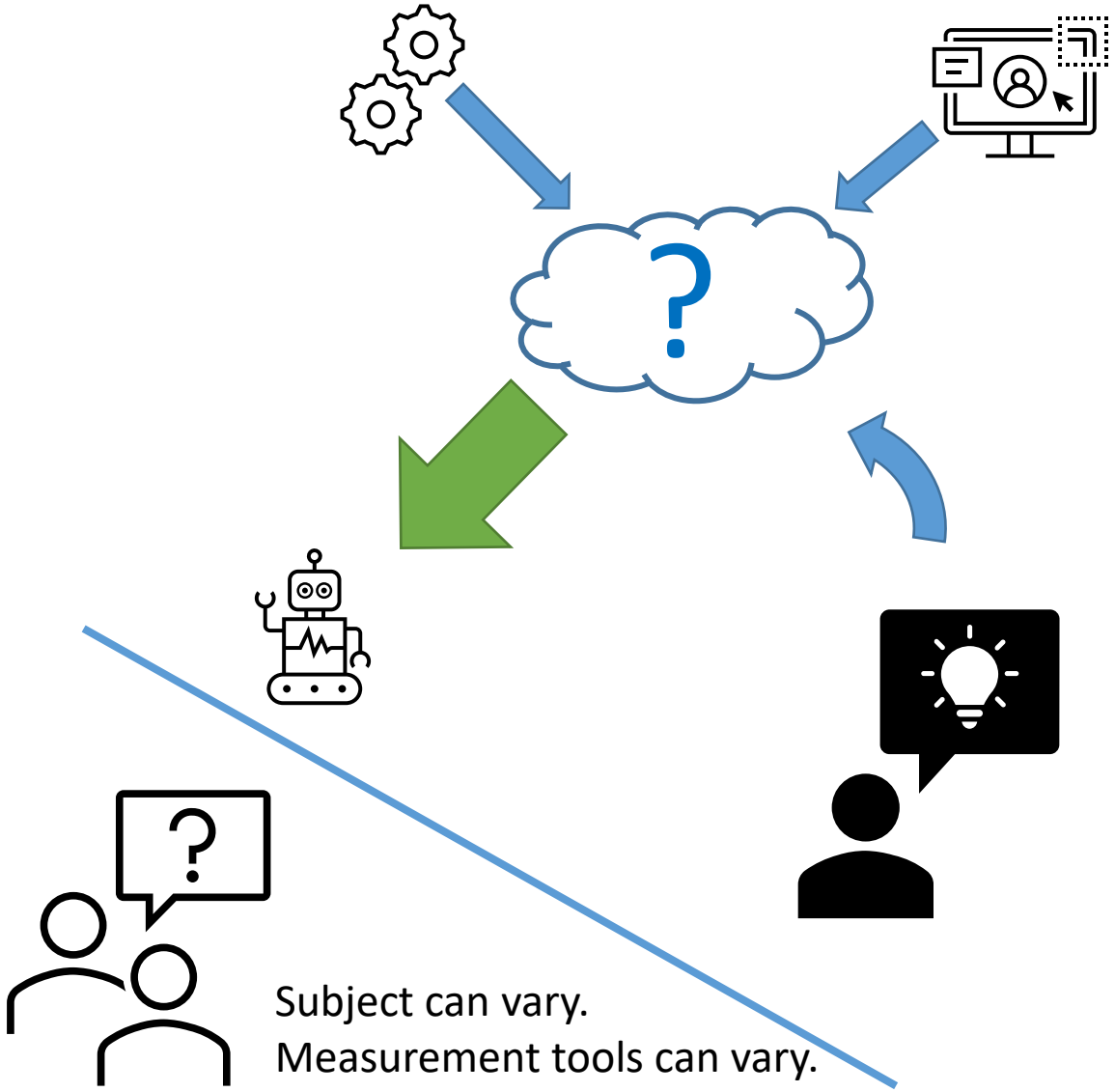
Increasing complexity

https://www.youtube.com/user/BostonDynamics/videos

Motivation: Reproducibility, Credibility



Subject (reality) is “fixed”
Measurement tools can vary.



Subject can vary.
Measurement tools can vary.

Motivation : EC FP7 - Open Questions for Robotics Research

1. How to decompose into components or sub-components?
2. How to evaluate a complex system?
3. How to define suitable metrics?
4. How to reproduce an experiment?
5. How to impose benchmarking as a scientifically recognised valuable activity?
6. How to benefit from standards without preventing innovation?

http://www.heronrobots.com/EuronGEMSig/downloads/Zaragoza/RSS2010-Benchmarking-AnneBAJART.pdf

Motivation : Good Experimental Methodology (GEM) Guidelines

Communication:

1. Is it an experimental paper?
2. Are the system assumptions / hypotheses clear?
3. Are the evaluation criteria spelled out explicitly?
4. What is being measured and how?
5. Is there enough information to reproduce the work?
6. Do the results obtained give a fair and realistic picture of the system being studied?
7. Are the drawn conclusions precise and valid?

http://www.heronrobots.com/EuronGEMSig/downloads/GemSigGuidelinesBeta.pdf

Motivation : Towards a Science of Robotics

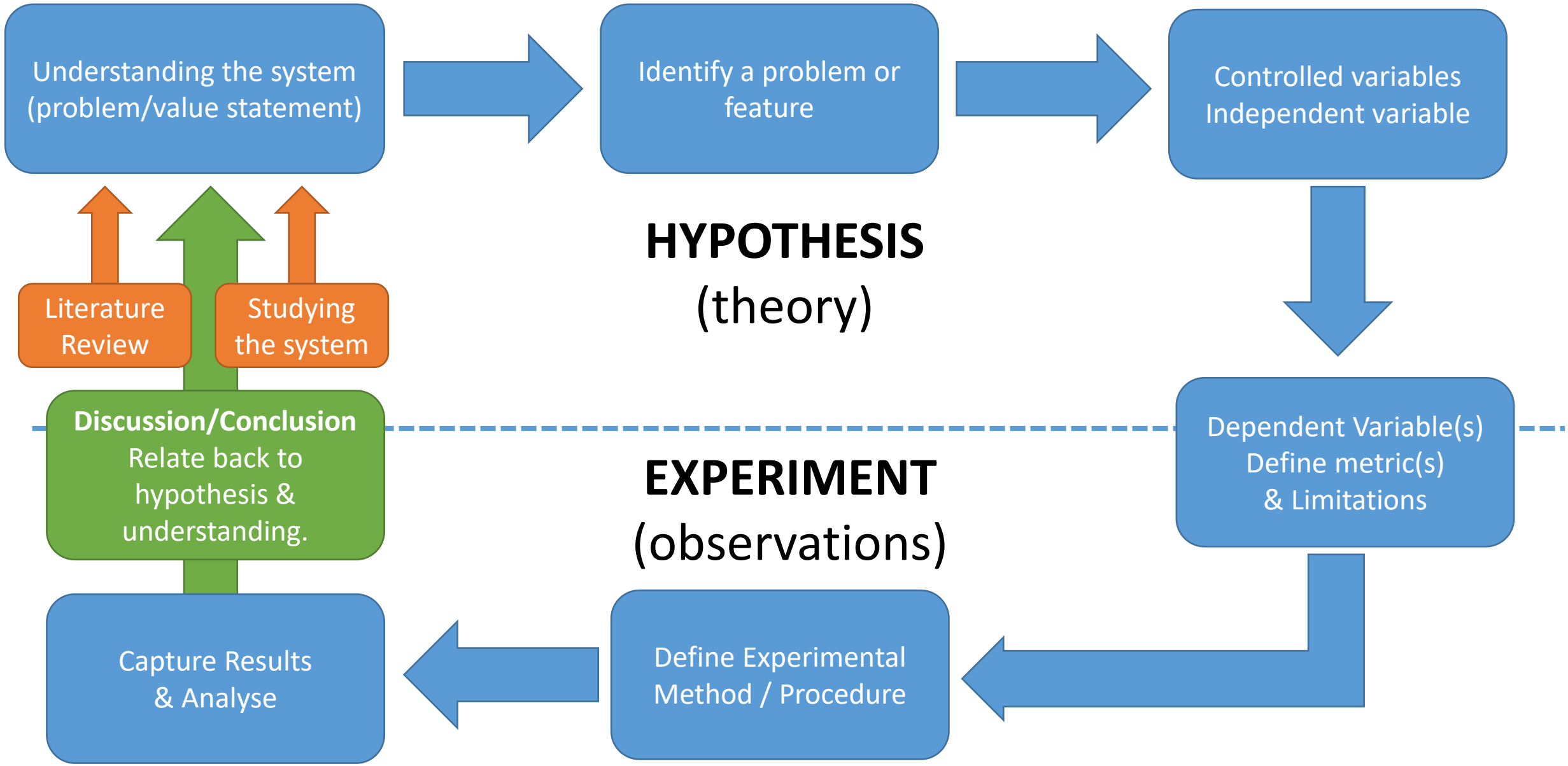
observable ***repeatable*** ***objective***

1. Use good measures, which are standardized and/or usable by others, and are as objective as possible.
2. Clearly and thoroughly explain the exact methods used to run the study so that others can reproduce the study to see if they get similar or different results.
3. Minimize subjectivity in experimental observations as much as possible.

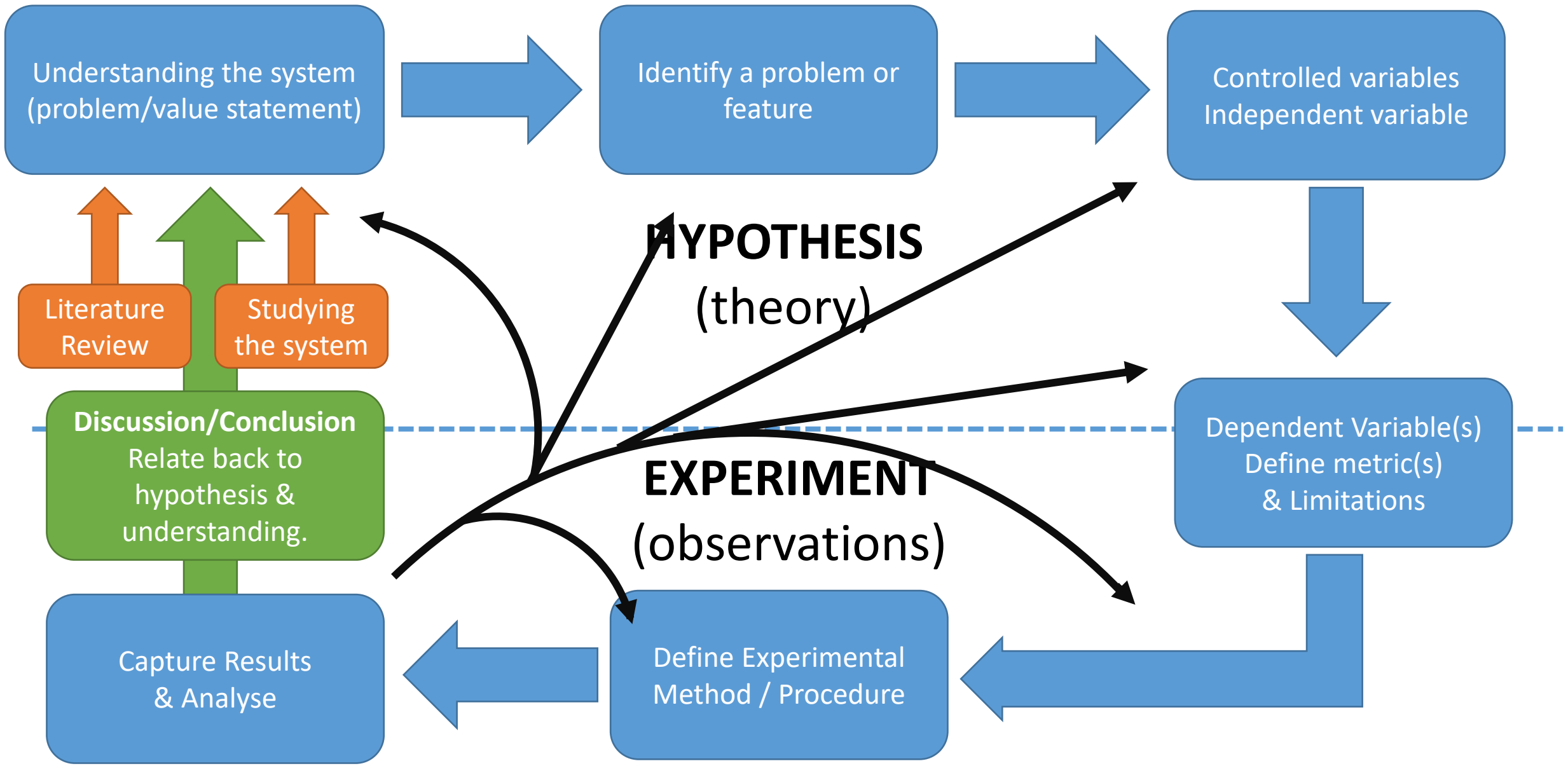
http://www.willowgarage.com/sites/default/files/TakayamaRSSworkshop.pdf

Experiments

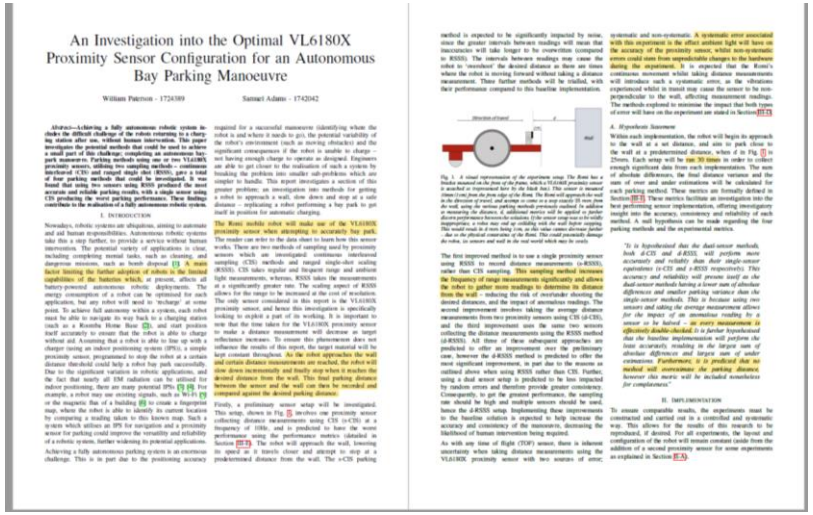
Experiment Overview



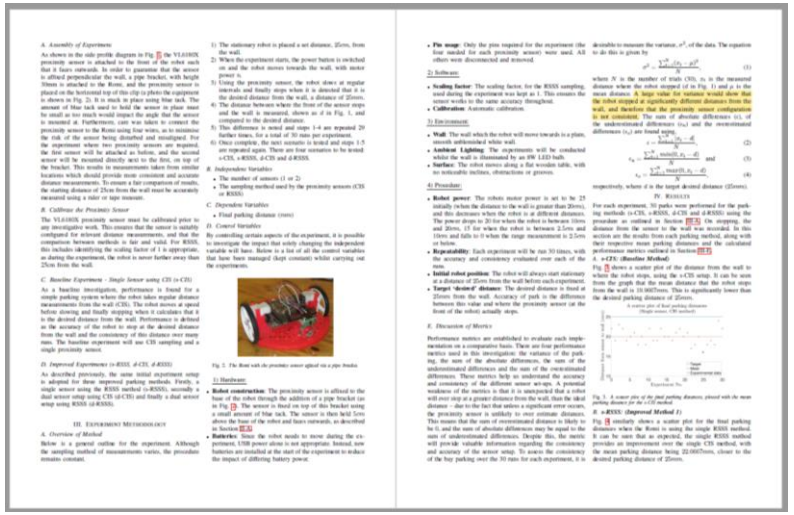
Experiment Overview, in practice.

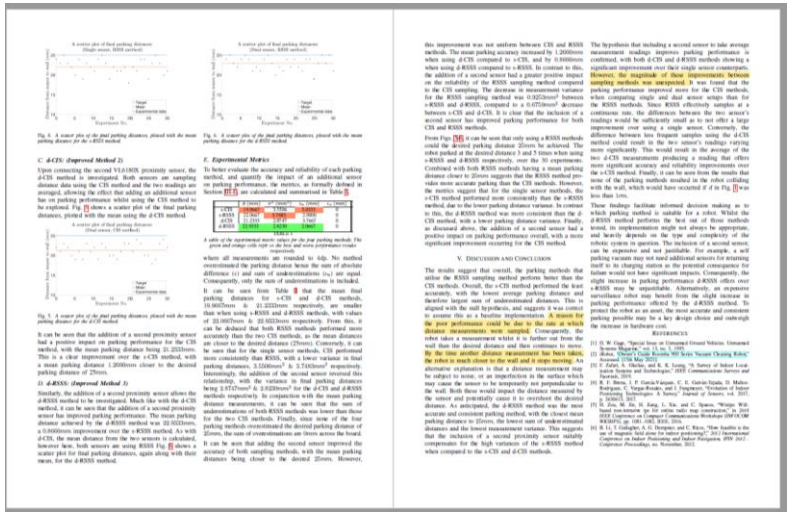


Reporting an Experiment


An Investigation into the Optimal VL6180X Proximity Sensor Configuration for an Autonomous Bay Parking Manoeuvre

William Paterson - 1724389 Samuel Adams - 1742042

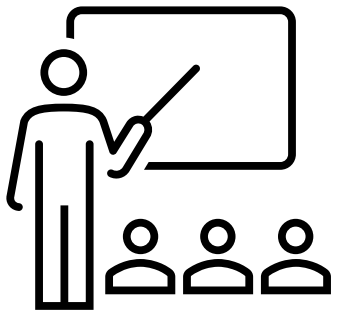




1. Why this study was undertaken (prior work?).
2. How this study was conducted.
3. How/why our results are credible.
4. The insight (learning) we demonstrate.
5. What it means, what we could do next.

Concise Report

~~Diary~~



"the reader"

"Should we include X?" → *"Does it justify / impact the study?"*

Types of Experiments in Robotics

Object-Centred ("engineering")

- Characterising a system, "empirical technology".
- Reveals opportunity and insight regarding technology.
- Comparing one technology to another, e.g., algorithm vs algorithm.

Variable Based ("science")

- Technologies informed by scientific understanding, "systematic technology".
- Common concepts between systems.
- Understanding / demonstrating the effect of a generalisable parameter or variable.

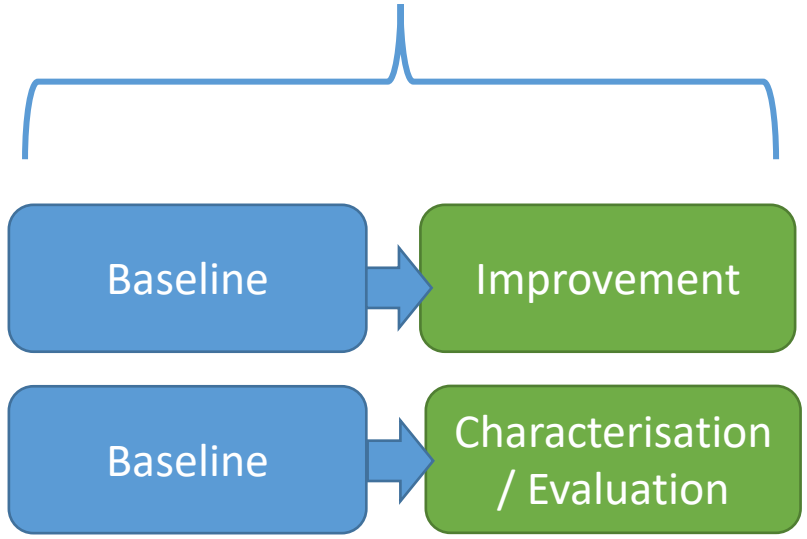
http://www.willowgarage.com/sites/default/files/TakayamaRSSworkshop.pdf

Types of Experiments in Robotics

Object-Centred ("engineering")

- Characterising a system, "empirical technology".
- Reveals opportunity and insight regarding technology.
- Comparing one technology to another, e.g., algorithm vs algorithm.

Compared against itself
Compared against similar system



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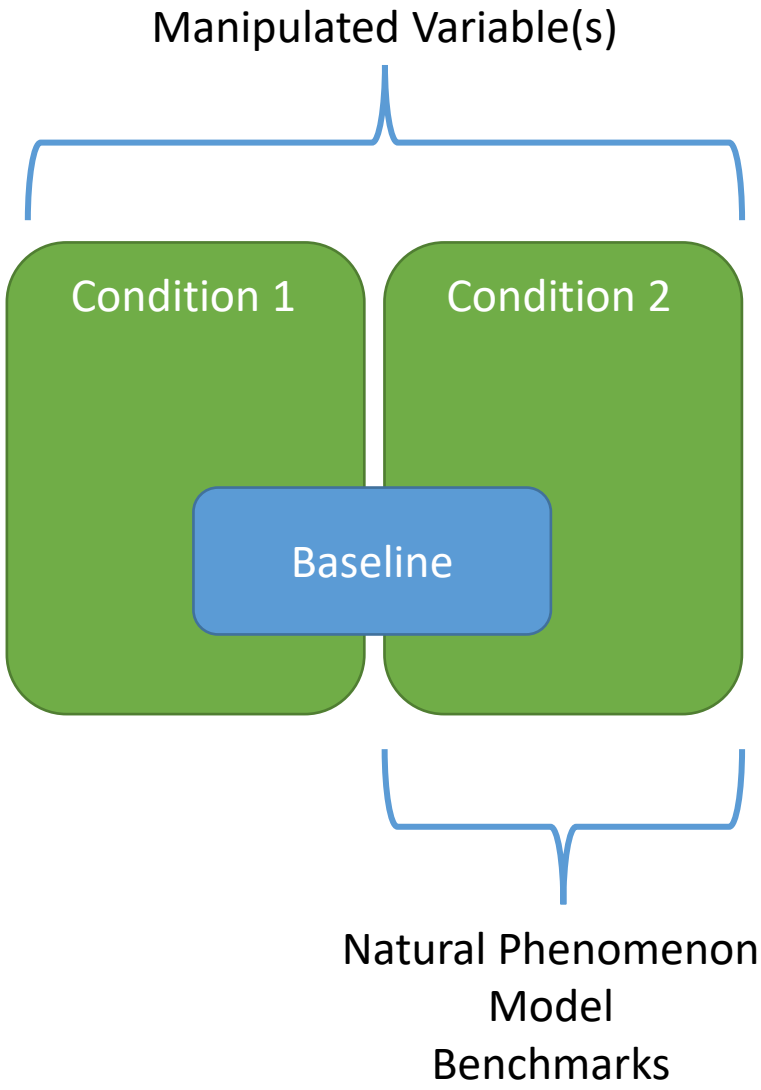

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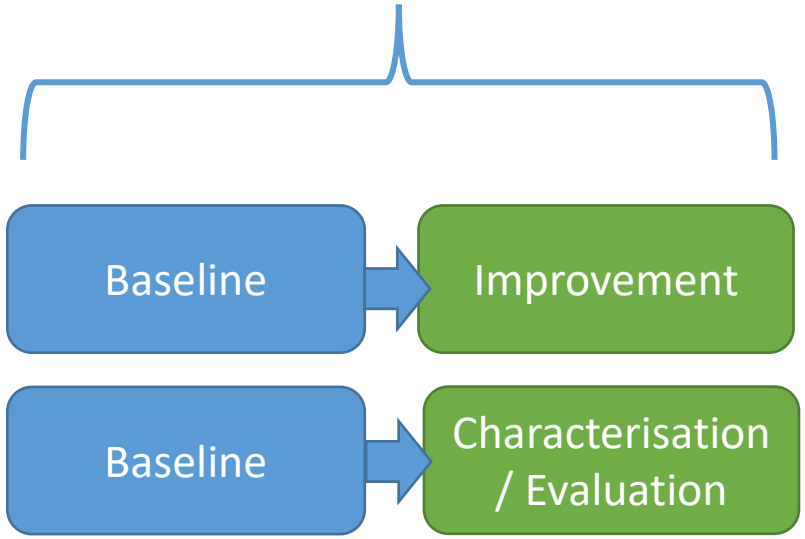
Types of Experiments in Robotics

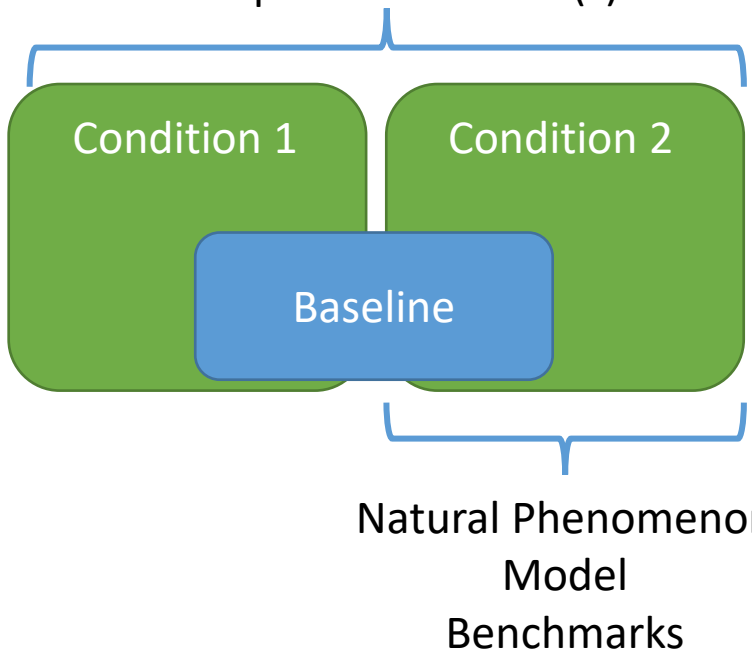
Variable Based & Object-Centred

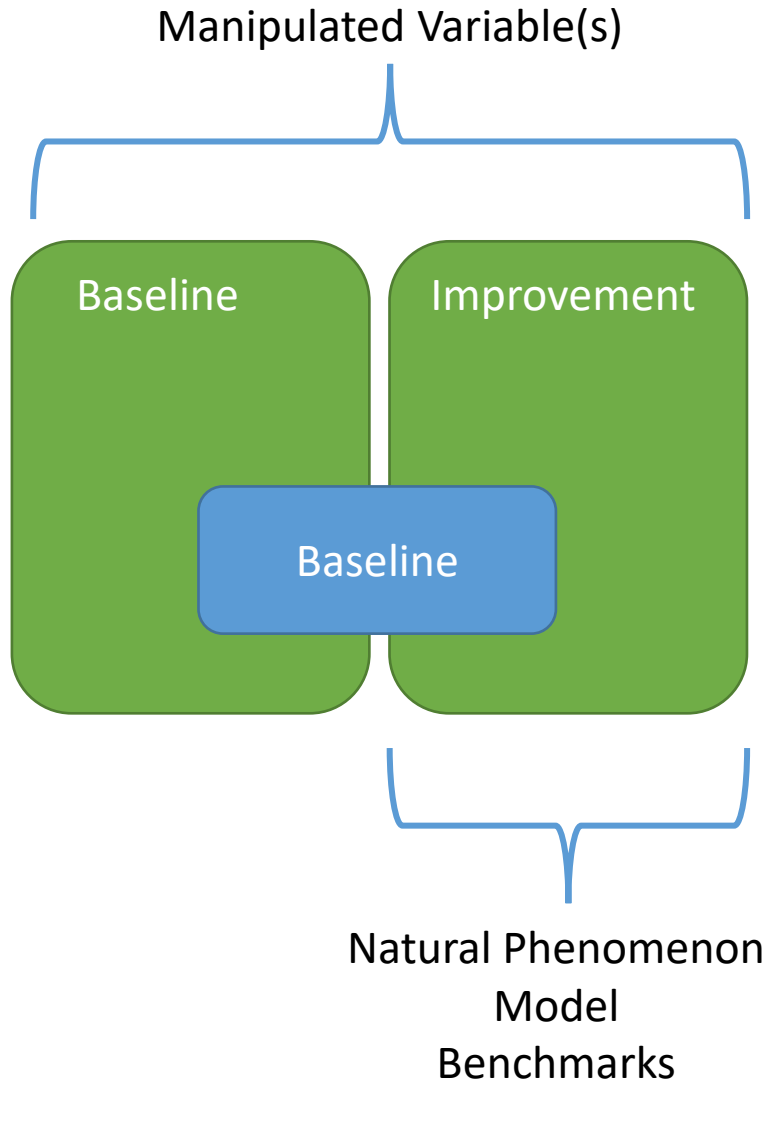
- We tend to do both in Robotics.
- Hence, communication is key.
- Better work is aligned to one.

Object-Centred:
Compared against itself



Variable Based:
Manipulated Variable(s)





Reporting

Reporting

Aims & Objectives
Context
Hypothesis

"what we think we can learn, how, and why it matters"

Implementation
Experiment Methodology
Metric(s)

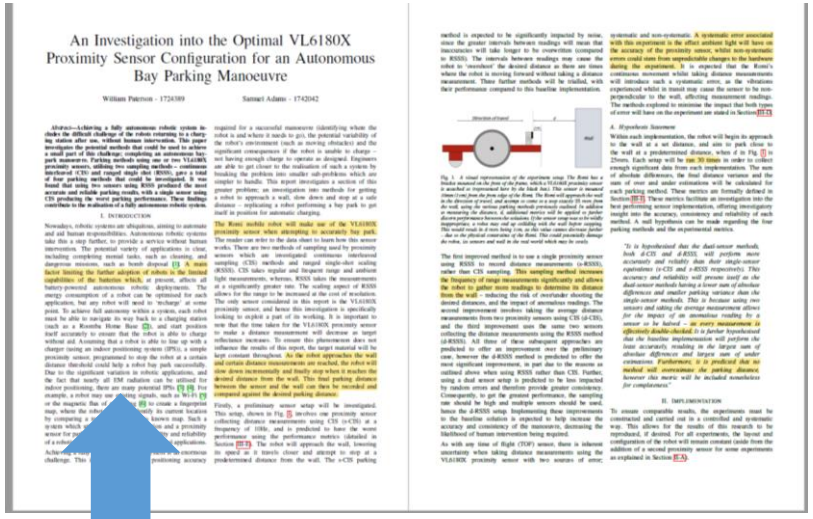
"how someone can recreate our work."
"how our results will be credible."

Results
Analysis

"what can be observed through the presentation of our data."

Discussion
Conclusion
Future Work

"whether we observed what we expected, and what we learnt."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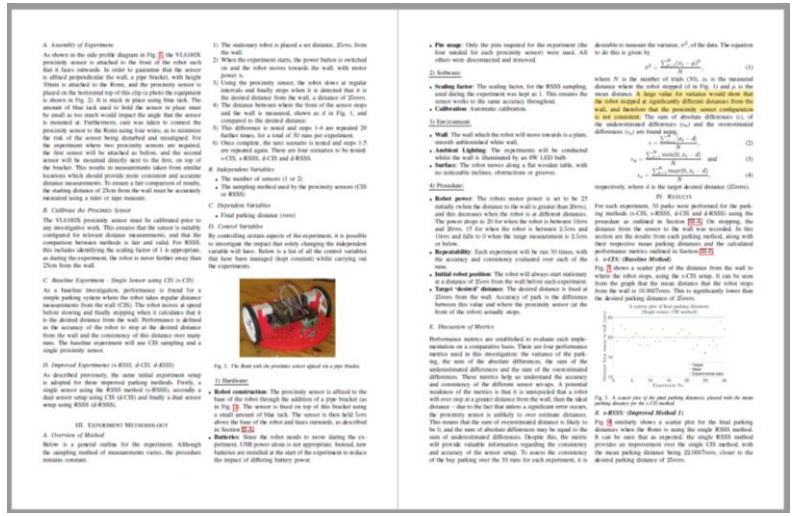

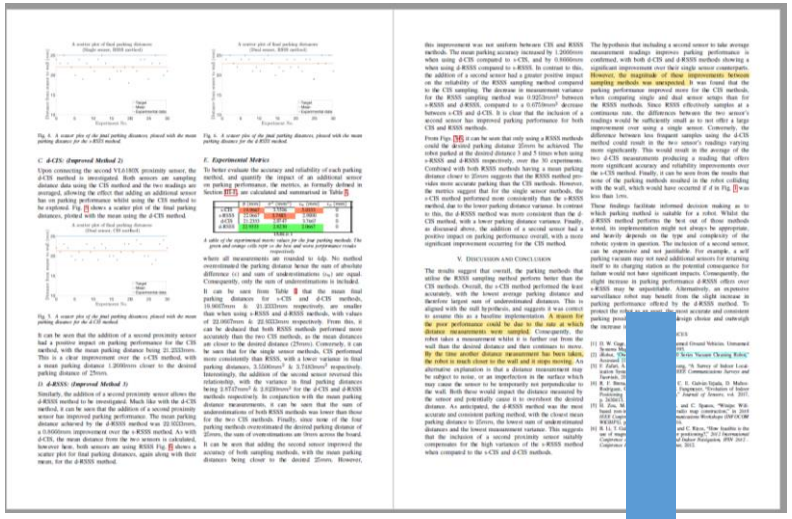

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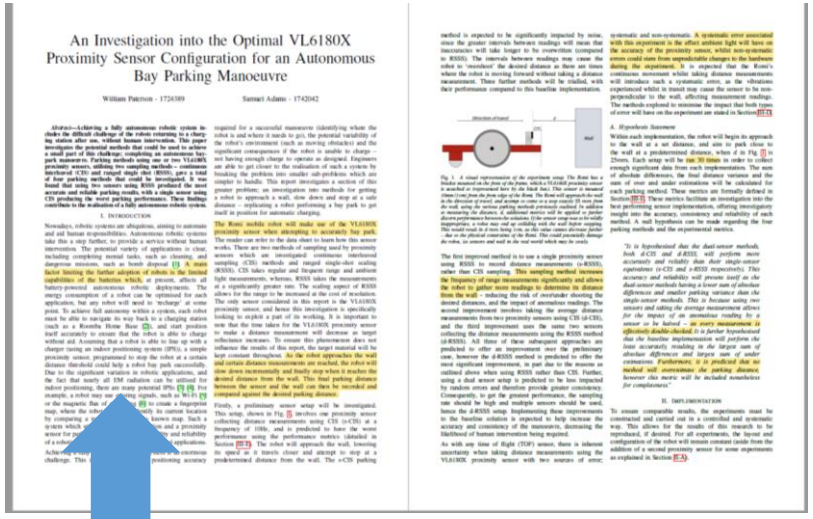
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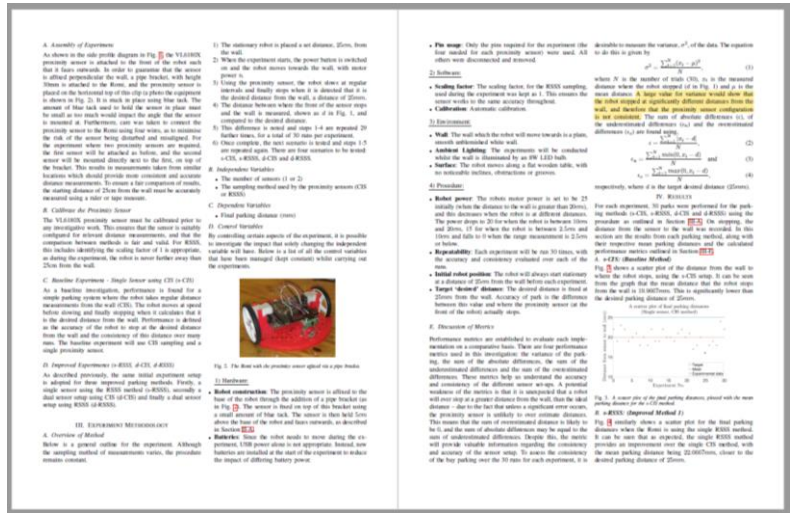

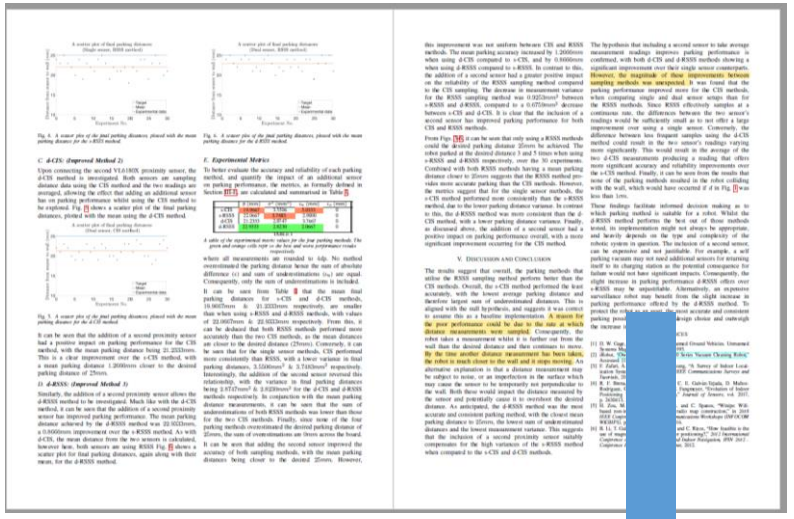

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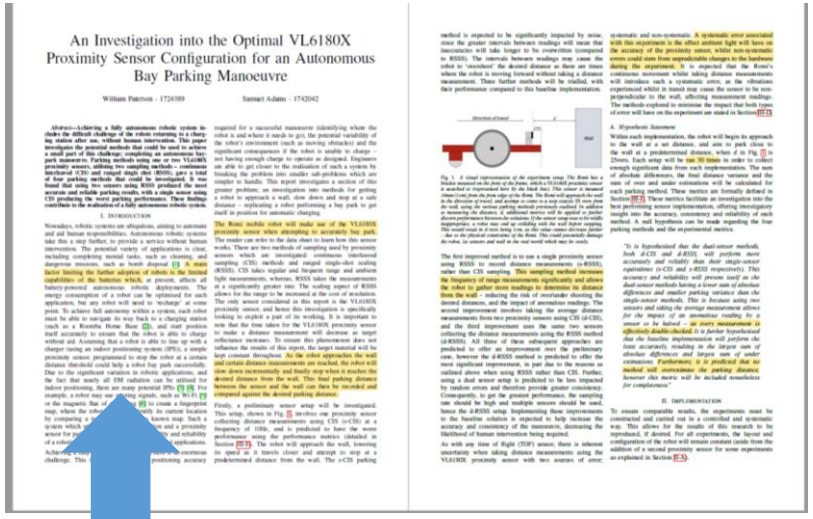
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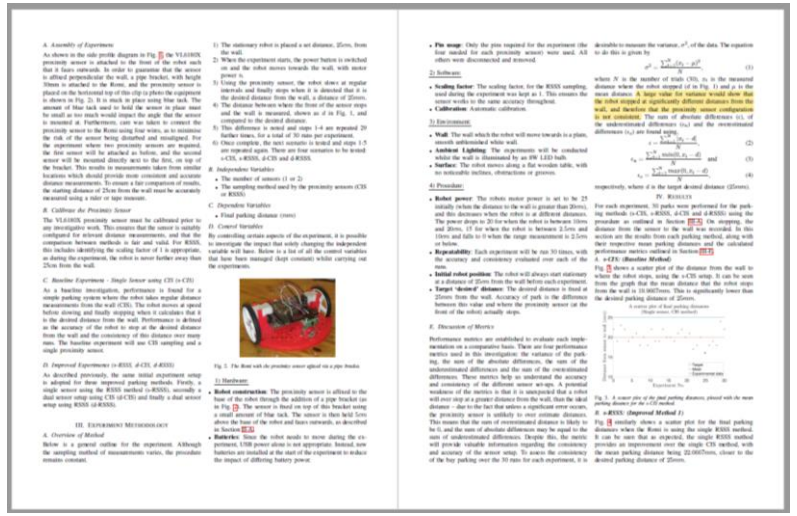

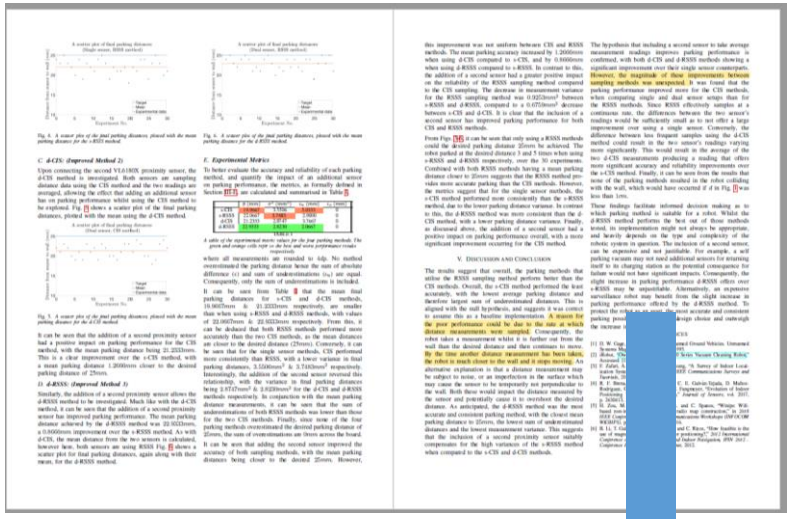

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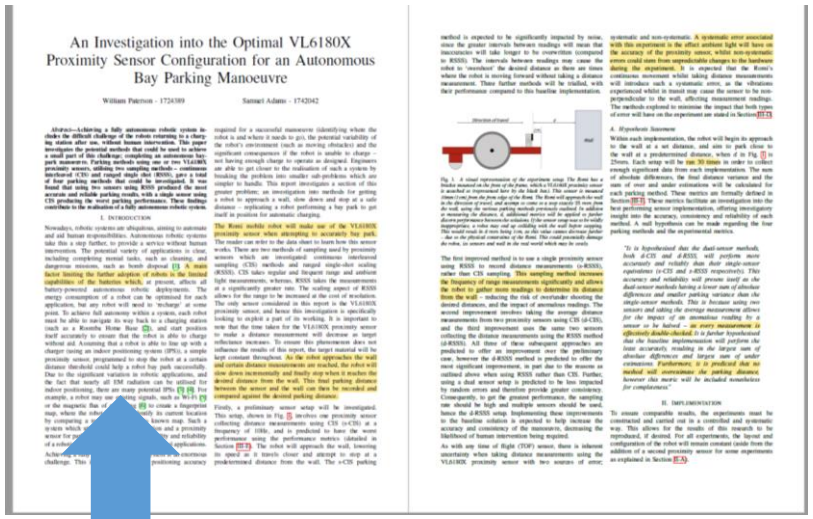
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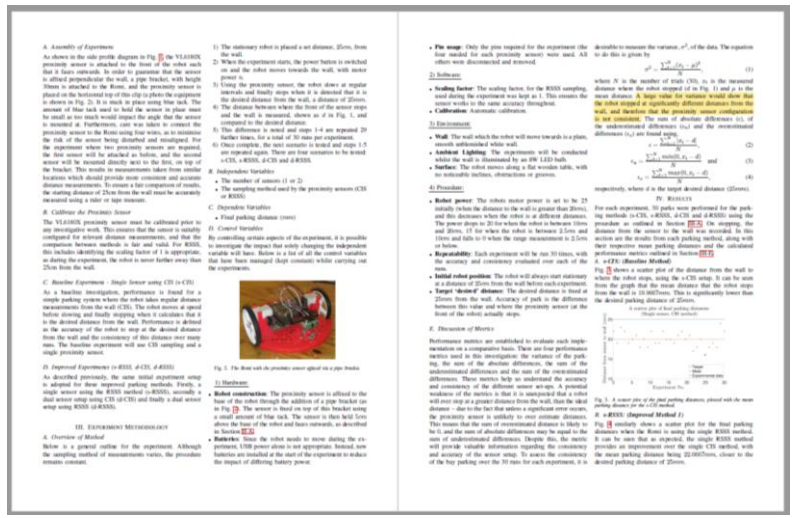

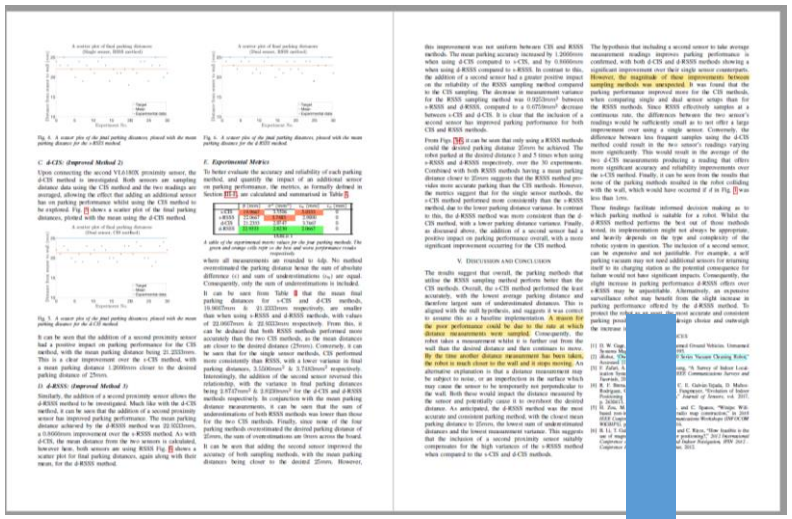

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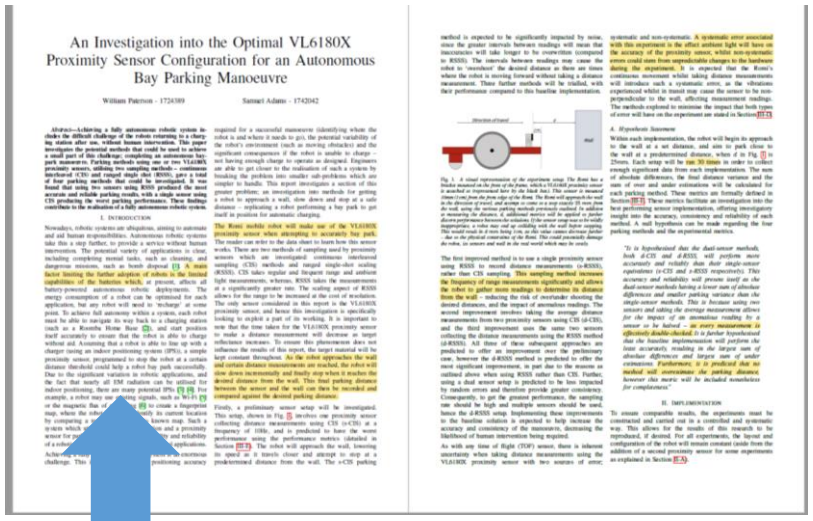
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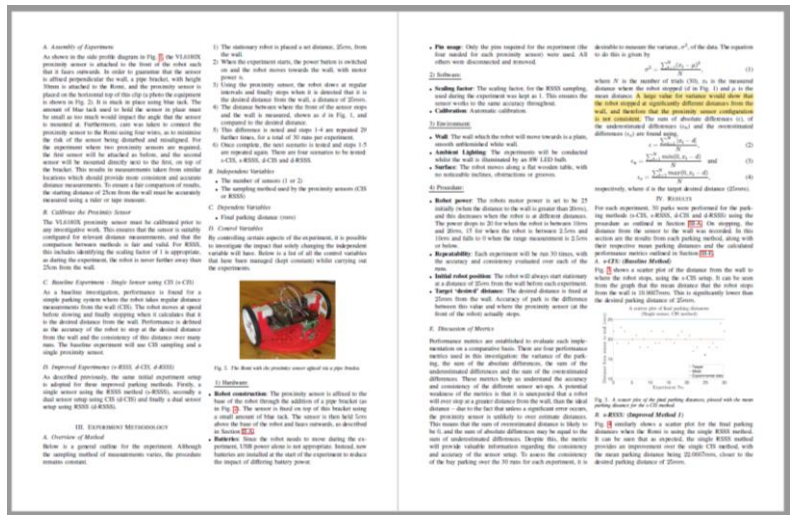

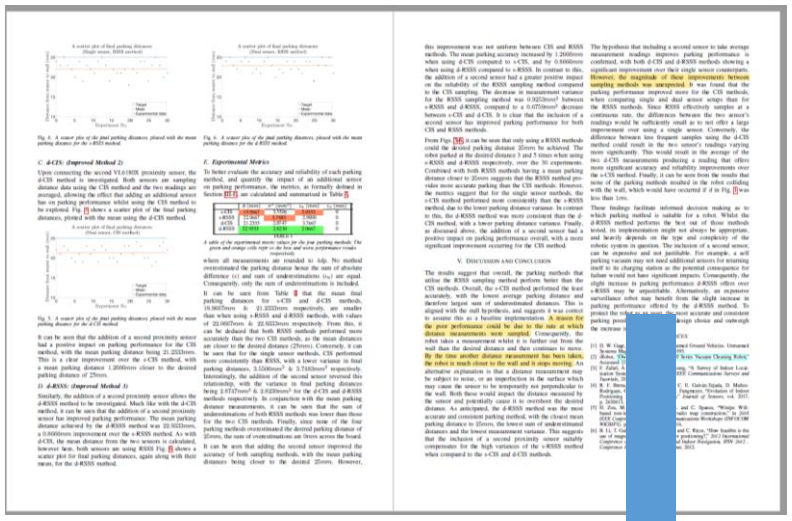

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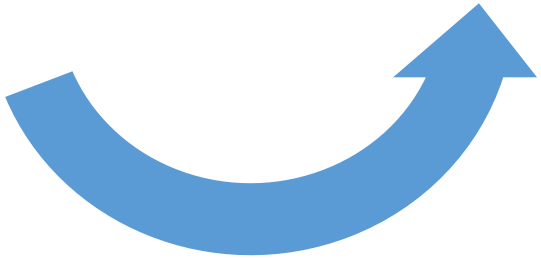

Discussion
Conclusion
Future Work

"whether we observed what we expected, and what we learnt."

"We thought we could <u>measure</u> (by doing)….

… and this is what we found."

- *Discuss anomalous results (e.g. outliers, or artefacts)*
- *Discuss how results demonstrate the element you are studying – what is learnt <u>precisely (objectively)</u>?*

Reporting

Aims & Objectives
Context
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"what we think we can learn, how, and why it matters"

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"We thought we could <u>learn</u> (by doing)….

… and this is what we found."

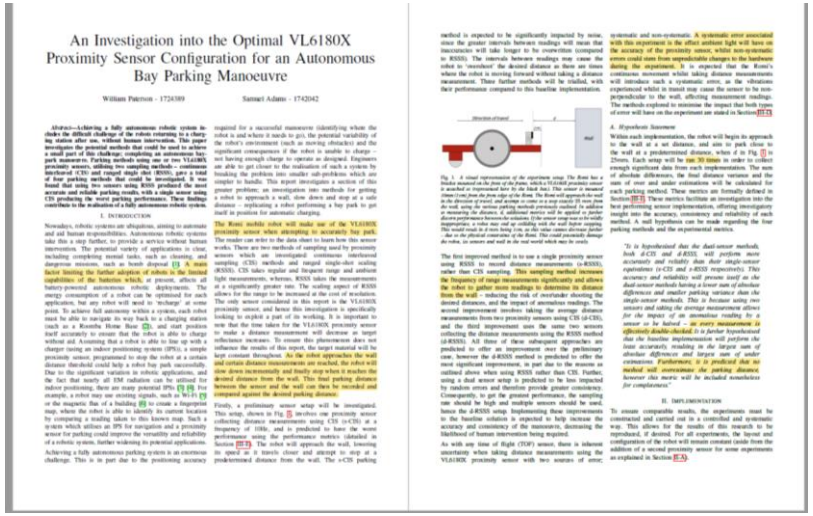
- *Re-state the hypothesis / research questions.*
- *Discuss the methodology, any success or limitations.*
- *Discuss how experiment demonstrates the element you are studying – what is learnt <u>generally</u>?*
  - *Interpretations (subjectivity) are better suited at this level.*

Aims, Objectives & Context

Reporting: Context, Aims & Objectives, Hypothesis

Aims & Objectives
Context
Hypothesis

"what we think we can learn, how, and why it matters"



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1. **Context:**
   a) any real-world relevance, existing work.
   b) Problem-statement: a task, challenge or feature.
   c) Value-statement: why it matters, or is of benefit.
2. **Aims:** what we hope to learn, or demonstrate as learnt.
3. **Objectives:** what is necessary to do or to implement (to learn).

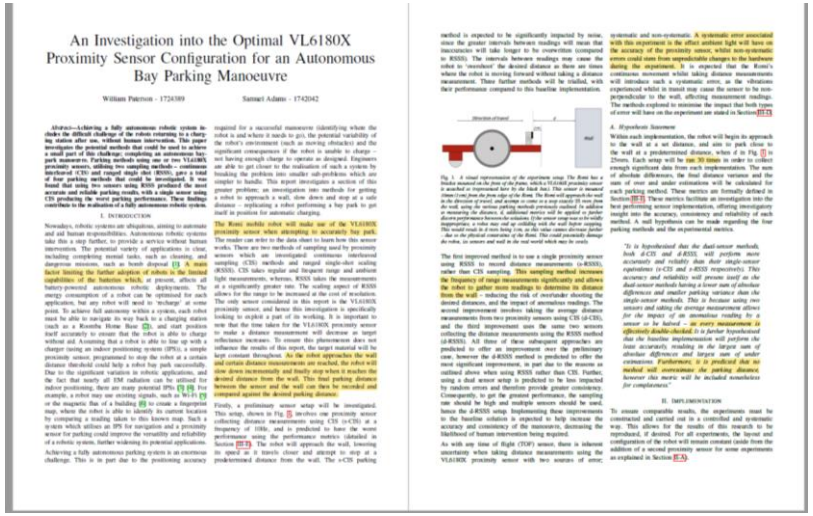
Preliminary Results:
Sometimes it is necessary to add preliminary results, findings or information to help the reader to understand the problem.
e.g., sensor performance, quantified system error(s), specifics to implementation that will effect the investigation.

4. **Hypothesis / Research Questions:**
   a) Given the information provided so far, what do we expect to observe?
   b) How can this be experimentally shown?

Reporting: Literature Review

Aims & Objectives
Context
Hypothesis

"what we think we can learn, how, and why it matters"



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Literature Review:

For EMATM0054 Robotic Systems:

- We are **not** expecting a comprehensive literature review.
- Use it to *give your reader the required understanding.*
- Reference where it helps:
  - 3Pi+ / Webots product page.
  - To save space on explaining any algorithm(s), etc.

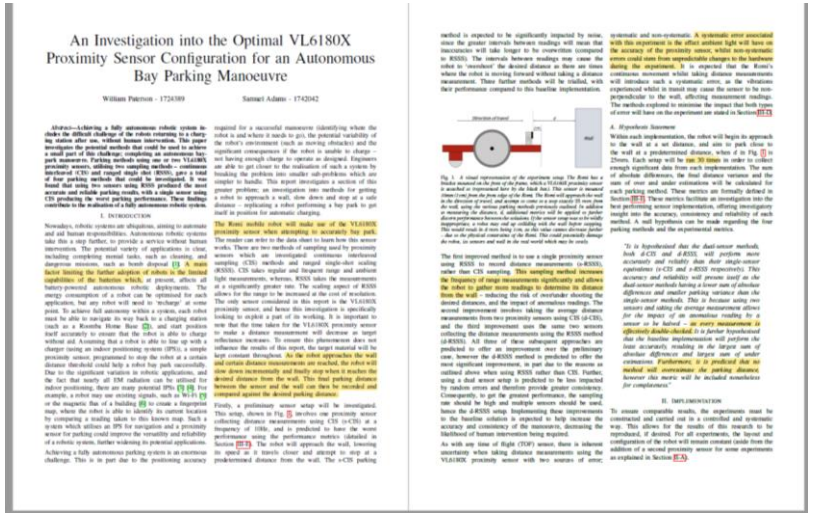
In the future: Use existing literature to support the value of your work.

- A literature review is **not** a collection of quotations.
- A literature review is **not** a catalogue of existing work.
- Your writing, review literature to assert your claim to novelty.

Reporting: Context, Aims & Objectives, Hypothesis

Aims & Objectives
Context
Hypothesis

"what we think we can learn, how, and why it matters"



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1. **Context:**
   a) any real-
   b) Prob
   c) Value-
2. **Aims:** what we
3. **Objectives:** what is necessary to do or to implement (to learn).

learnt.

Build the readers knowledge to understand your hypothesis / questions (and then method, etc)

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Sometimes it is necessary to add liminary results, findings or information to help the reader to derstand the problem. e.g., sensor performance, quanti system error(s), specifics to implementation that will effect t investigation.

4. **Hypothesis / Research Questions:**
   a) Given the information provided so far, what do we expect to observe?
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Implementation, Method

Reporting: Implementation, Method

Implementation
Experiment Methodology
Metric(s)

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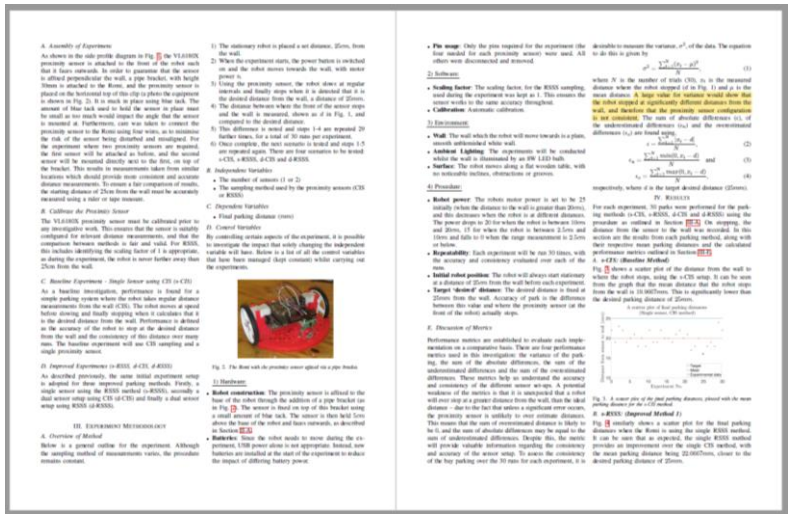


1. **Implementation:**
   a) What hardware was used, how/why was it physically configured?
   b) What software was used, how/why was it configured?
   c) What software was implemented? Architecture, system diagrams, pseudo-code, etc.
2. **Experiment Methodology:**
   a) Controlled Variables: fixed parts of the experiment to isolate one part being investigated.
   b) Independent Variable(s): Ideally, only 1 per scenario. (input, thing we change).
   c) Dependent Variable(s): aspects which are measured (output, thing we measure).

Experiment Procedure:

a) Necessary human behaviours/actions to mitigate human error.

3. **Metrics:**
   a) Dependent variable(s) (raw data) may need to be processed or combined to make them useful. This should be justified, with any limitations discussed.
   b) The best metrics would transfer to other robotic systems (benchmarks)

Implementation: Diagrams, Pseudo-Code, Photos

Reproducible?

Algorithm 1 Avoidance

```
1:  procedure ObstacleAvoidance
2:      distance_threshold ← 200.0 − 85.0
3:      Line_Following :
4:      Follow Line
5:      if distance_to_obstacle > distance_threshold then
6:          Find_Corner :
7:          Rotate Left
8:          if CornerDetected then
9:              Calculate Corner Position
10:             Calculate Romi Offset Position
11:             Drive to Offset Position
12:             if LineDetected then
13:                 goto Line_Following
14:             Point at Corner position
15:             goto Find_Corner
```

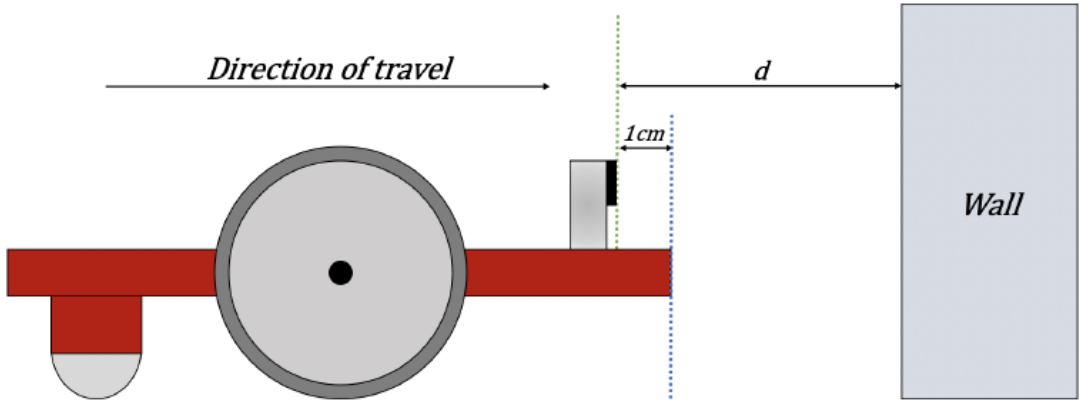


Fig. 1. *A visual representation of the experiment setup. The Romi has a bracket mounted on the front of the frame, which a VL6180X proximity sensor is attached to (represented here by the black box). This sensor is mounted 10mm (1cm) from the front edge of the Romi. The Romi will approach the wall*

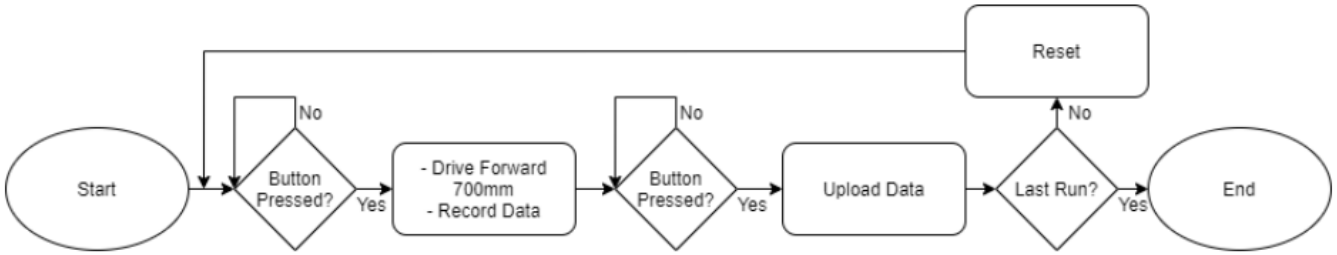


Fig. 4. Code Flowchart

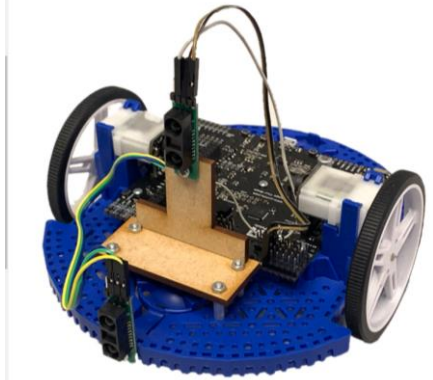


Fig. 3: An image of the Pololu Romi 32U4 used to carry

Method: Variables (bad)

~~**Independent**~~
Uncontrolled
(changing)

Dependent
(measured)

Implementation?

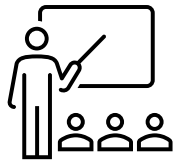
Task environment?

Human factors?

Exp. Method?

Robotic System
(task, software, hardware, environment)

Data / Results



"what is the relationship?"
"what do we observe / learn?"

Method: Variables (ideal)

Independent
(manipulated)

Controlled
(fixed aspects)

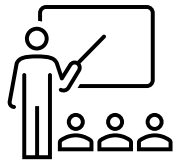
Dependent
(measured)

Fix anything else that will effect results.

Ambient Light Level

Robotic System
(task, software, hardware, environment)

Data / Results



"what is the relationship?"
"what do we observe / learn?"

Method: Variables (confounding)

Independent
(manipulated)

Controlled
(fixed aspects)

Dependent
(measured)

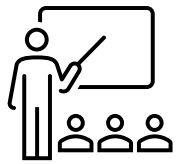
Anything else that will effect results.

Ambient Light Level

Manufacturing Tolerance

Robotic System
(task, software, hardware, environment)

Data / Results



"what is the relationship?"
"what do we observe / learn?"

REPEATED TRIALS

Method: Variables (confounding, increasing complexity)

Scenario 1

Independent
(manipulated)

Controlled
(fixed aspects)
Anything else that will effect results.

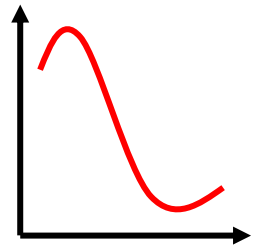
Dependent
(measured)

V1: Ambient Light Level

Robotic System
(task, software, hardware, environment)

Velocity (fixed)

Data Results



Scenario 2

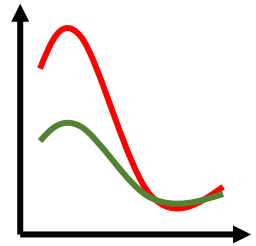
Anything else that will effect results.

V1: Ambient Light Level

V2: Velocity

Robotic System
(task, software, hardware, environment)

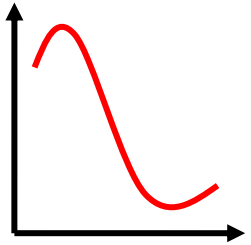
Data Results



Method: Variables (increasing complexity)

Scenario 1

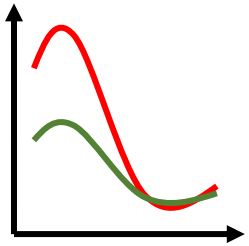
V1: Ambient Light Level



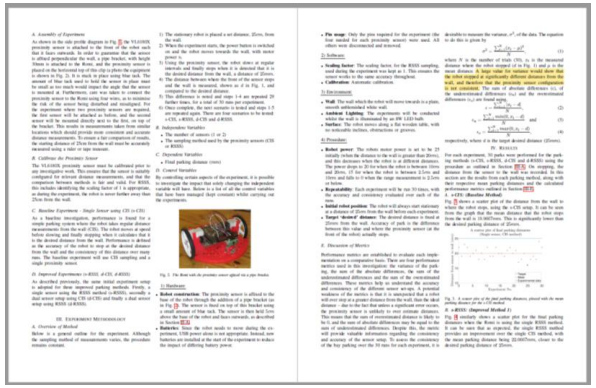
Scenario 2

V1: Ambient Light Level

V2: Velocity

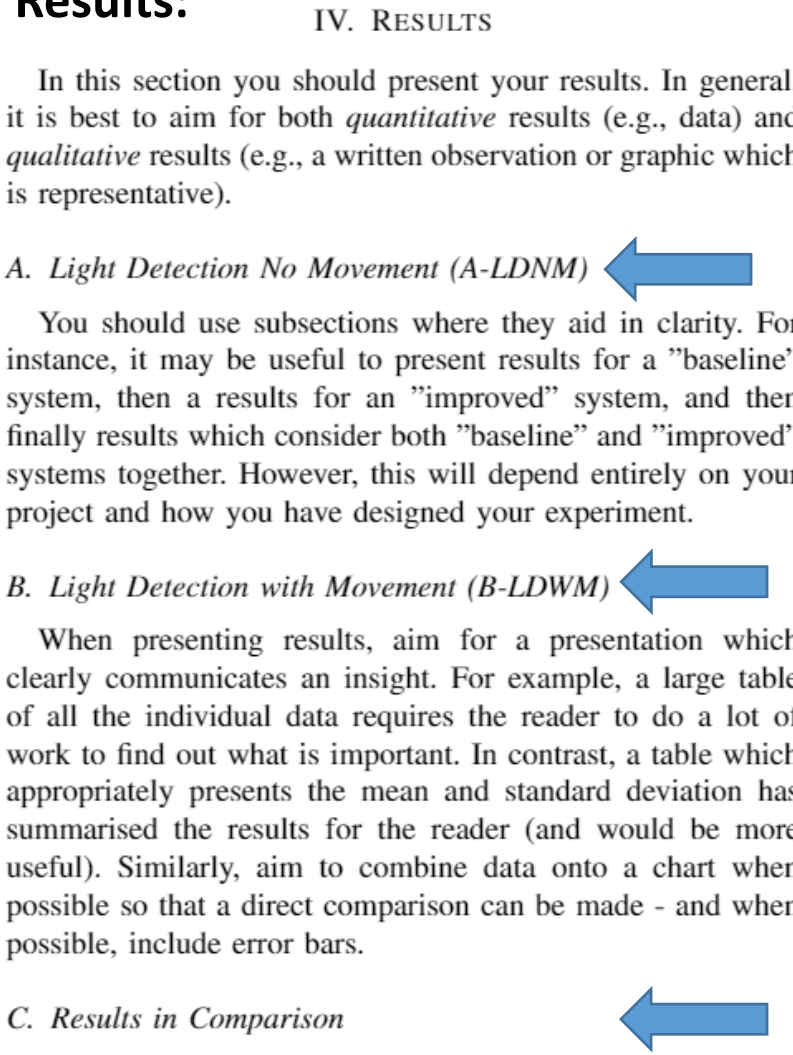


Experiment Methodology:



"We conduct two experiment scenarios. First scenario A *light-detection-no-movement* (A-**LDNM**), and scenario B *light-detection-with-movement* (B-**LDWM**)."

Results:



IV. Results

In this section you should present your results. In general it is best to aim for both *quantitative* results (e.g., data) and *qualitative* results (e.g., a written observation or graphic which is representative).

A. Light Detection No Movement (A-LDNM)

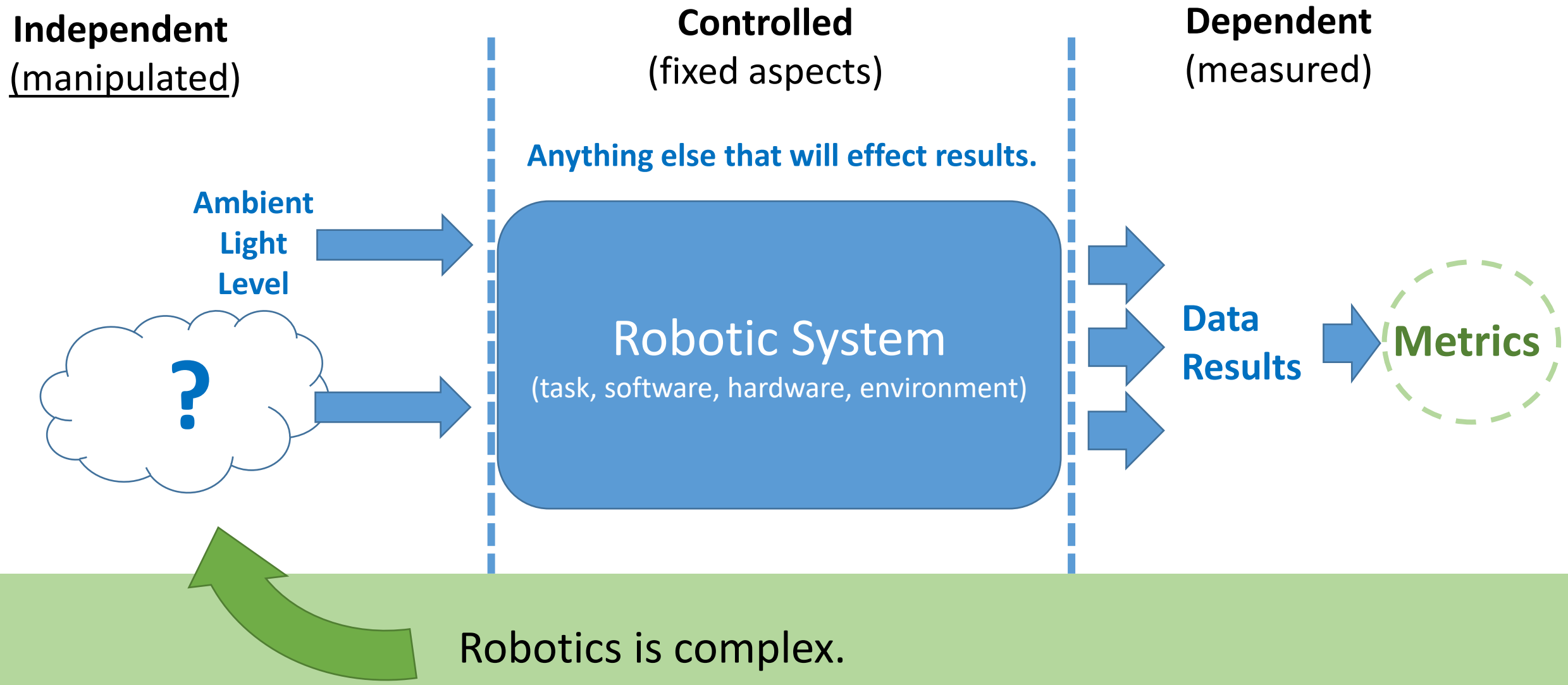
You should use subsections where they aid in clarity. For instance, it may be useful to present results for a "baseline" system, then a results for an "improved" system, and then finally results which consider both "baseline" and "improved" systems together. However, this will depend entirely on your project and how you have designed your experiment.

B. Light Detection with Movement (B-LDWM)

When presenting results, aim for a presentation which clearly communicates an insight. For example, a large table of all the individual data requires the reader to do a lot of work to find out what is important. In contrast, a table which appropriately presents the mean and standard deviation has summarised the results for the reader (and would be more useful). Similarly, aim to combine data onto a chart where possible so that a direct comparison can be made - and where possible, include error bars.

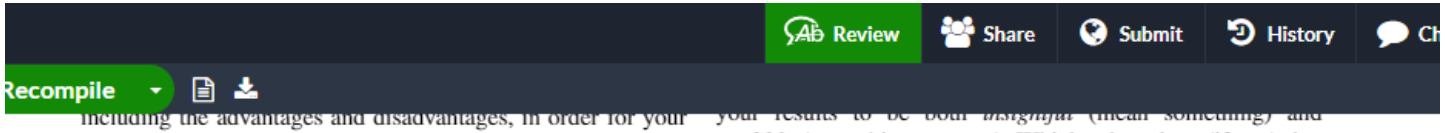
C. Results in Comparison

Method: Variables (confounding)



Robotics is complex.
Confounding variables are typically present.

Method: Variables



including the advantages and disadvantages, in order for your reader to properly understand the *value* of your investigation. You want your reader to agree that this is an interesting project, as well as for your reader to understand *why*.

You are encouraged to use specialist language and concepts covered in the unit to explain the background context of your project. Where relevant, you are encouraged to reference external sources of information, such as technical datasheets, online articles [1] [2], or academic literature. Try to write your report both to explain your experiment well and to demonstrate what you have learnt, what you understand about the results and their causes.

A. Hypothesis Statement

Because formulating a hypothesis is central to this assessment, it is recommended you write your hypothesis into a clear subsection (this subsection) as specified in this report template. Because you have introduced your work well above (providing key background context and specialist knowledge) you can be quite literal here with your hypothesis. For example:

Because the VL1680X has been identified as an active sensor with ... limitations, we hypothesise that:

> by applying ... filtering to the sensor, we predict a measurable improvement of the sensor under ... conditions.

We investigate this hypothesis through a structured experiment on the Romi mobile robot, comparing the performance of the sensor with and without our technique.

II. Implementation

In this section you should describe the specifics for your implementation such that your reader could recreate your work. If you have used a well understood algorithm or technology you can reference an external source, unless explaining the

your results to be both *insightful* (mean something) and *credible* (not subject to error). Which subsections (if any) that you use in this section will largely depend on your project and how you choose to present it. The following are suggestions to aid the clarity of your work.

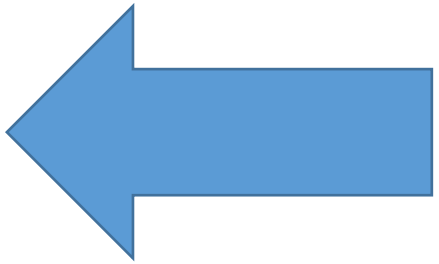
A. Overview of Method

Describe to the reader the general structure and procedure of your experiment. You should provide a specification a bit like a cake recipe. For example: how long does your experiment last? how many repeated trials do you use? how many alternate scenarios are there?

B. Discussion of Variables

You should outline the key variables within your experiment. This will help your reader to later believe your results are credible and not confused.

- **Controlled Variables**: These are the parts of your experiment (task, hardware, software, environment) which *could* vary, but which you have controlled by careful design of your experiment. For example, battery life varies, so you will use new batteries.
- **Independent Variable**: This is the part of your experiment which you are changing so that you hope to observe a measurable alteration in performance. Note that, we ever only want one independent variable - sometimes we aim for this, but concede other parts will change, and we need to make careful analysis of our system and/or results.
- **Dependent Variable(s)**: These are the part(s) of your experiment in which you hope to observe a measurable change. You will design or select appropriate *metrics* to measure and analyse this dependable variable. For example, we can have one dependent variable of the



Guidance in the Report Template

Metrics

Metrics: Giving Context

Raw Data

6328	6284	6284	6288
6116	6096	6112	6136
6156	6156	6156	6156
5848	5856	5844	5856
5788	5792	5784	5792
5136	5116	5120	5140
4660	4632	4640	4636
4076	4096	4076	4072
3860	3876	3860	3860
3076	3080	3080	3076
2664	2664	2672	2664
2648	2644	2648	2644

Dependent Variable(s)

Measurement Sources:

X, Y, theta

Velocity

Acceleration

Trajectory

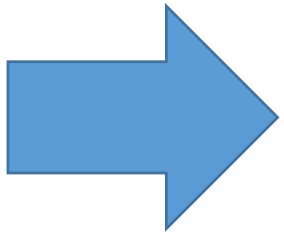
Sensor Activation

Mapping

Internal States

Environment Interactions

Time

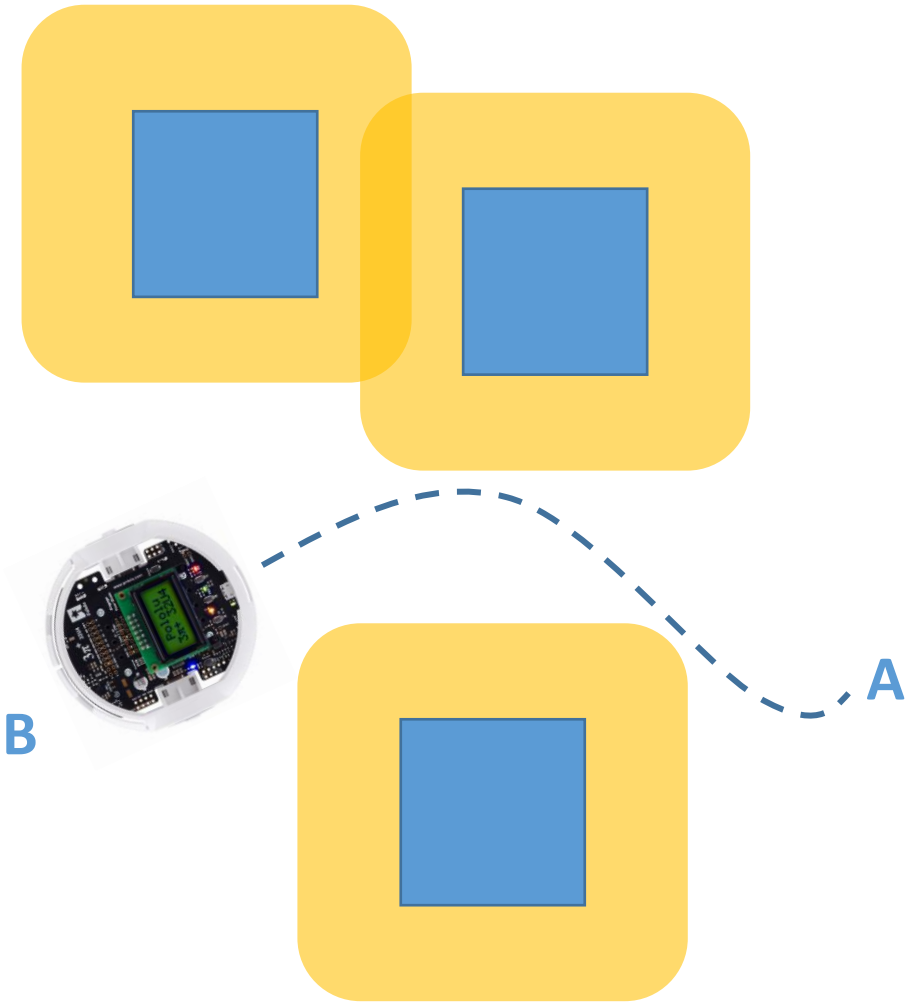


Metric (context):

- What does the data show/represent?
- How can the data be put in context?
- How can data be combined to be offer more robust insight?
  - What is hidden or obscured in a collection of data?
  - What are common trade-off's between measurements? (e.g., cost-benefit)

Metrics: Example

Mobile Robot Navigation



- **Mean-Distance between robot and obstacles (over time):**
  - a measure of time spent in obstruction free areas.
- **Mean Minimum-Distance to obstacles (over time):**
  - closest encounter, the risk of collision
- **Minimum Distance (instantaneous):**
  - Single minimum distance, most significant risk taken.
- **Mean Distance to Goal (over time):**
  - Efficiency of path against an ideal path.
- **Trajectory Smoothness:**
  - Efficiency of decision making with respect to obstructions or navigation.

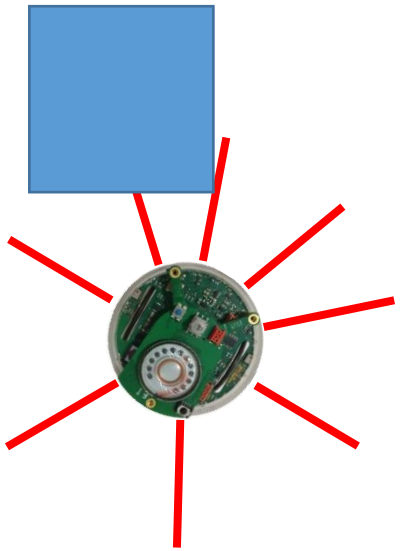
Metrics (& Benchmarks): Example

$$score = \frac{1}{n}\sum_{t=1}^{n}(V_t * \Delta V_t * S_t)$$

[0.0 : 1.0]

we might be able to compare different robots

Obstacle Avoidance



Dependent Variable(s)

Wheel Velocity

[-max : + max]

Sensor Activation

[min : max]

Normalised

[-1.0 : +1.0]

[0.0 : +1.0]

Metric Components

Absolute motion:

$$V = \frac{|V_{left}| + |V_{right}|}{2}$$

Rotation:

$$\Delta V = 1 - |((V_{left} + 1.0) * 0.5) - ((V_{right} + 1.0) * 0.5)|$$

Sensor Activation, max across sensors i = [0:7]:

$$S = 1 - max(i)$$

Metrics: Giving Context

Raw Data

6328	6284	6284	6288
6116	6096	6112	6136
6156	6156	6156	6156
5848	5856	5844	5856
5788	5792	5784	5792
5136	5116	5120	5140
4660	4632	4640	4636
4076	4096	4076	4072
3860	3876	3860	3860
3076	3080	3080	3076
2664	2664	2672	2664
2648	2644	2648	2644

How to give context to results?

De

Me

X, Y, t

Velocity, Acceleratio

Trajectory

Sensor Activation

Mapping

Internal State

Environme

Interact

Time

ntext):

does the data show/represent?

How can the data be put in context?

- How can data be combined to be offer more robust insight?

hat is hidden or obscured in a collection

?

What is the important context for your study?

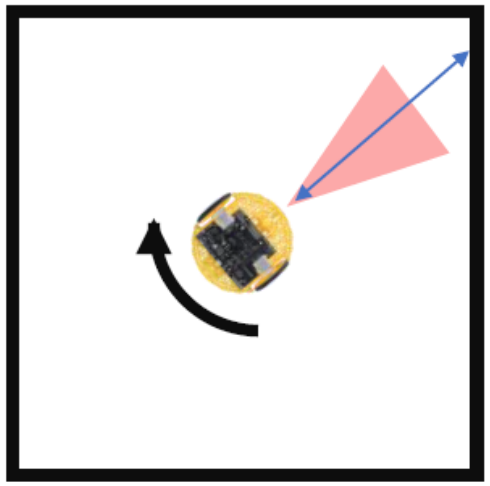
e common trade-off's between

ements? (e.g., cost-benefit)

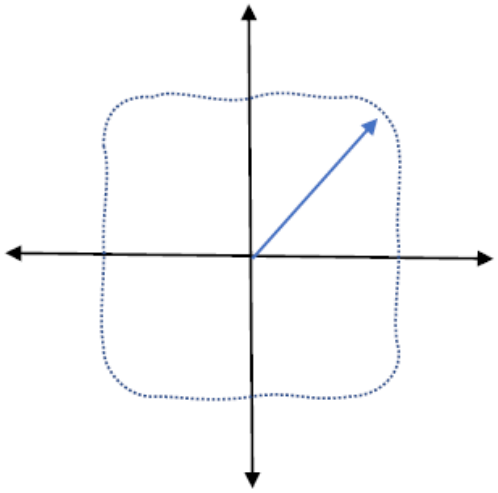
Results

Data: What do we learn?

Ground Truth



Mapping Results (Polar Plot)



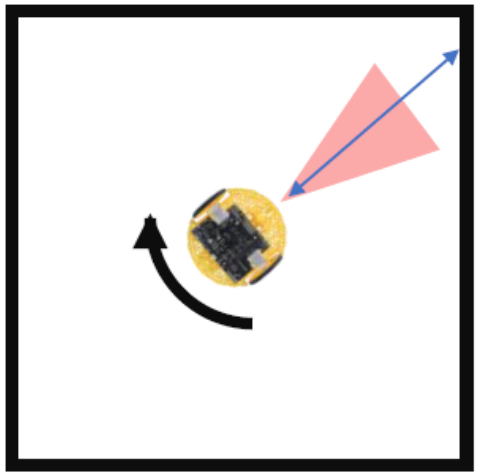
Data

Angle (Degrees)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9
0	15mm	17mm	14mm	15mm	18mm	15mm	11mm	12mm	13mm
1	14mm	14mm	15mm	12mm	15mm	15mm	11mm	12mm	13mm
2	12mm	12mm	11mm	15mm	12mm	15mm	11mm	12mm	13mm
3	13mm	13mm	14mm	14mm	16mm	15mm	11mm	12mm	13mm
4	15mm	13mm	12mm	12mm	14mm	15mm	11mm	12mm	13mm
5	15mm	13mm	16mm	16mm	13mm	15mm	11mm	12mm	13mm
...	...	...	...	...	...	..	...	...	...

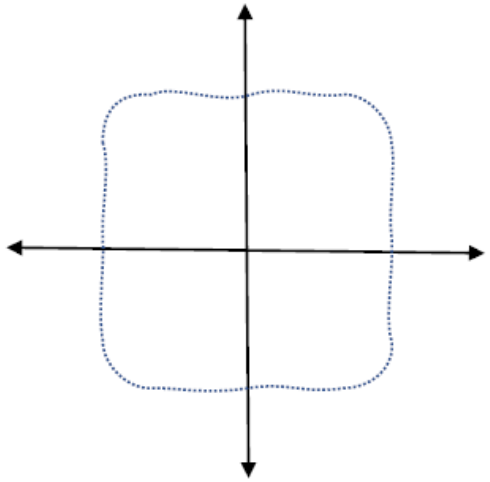
What do we learn...?

Data: What do we learn?

Ground Truth

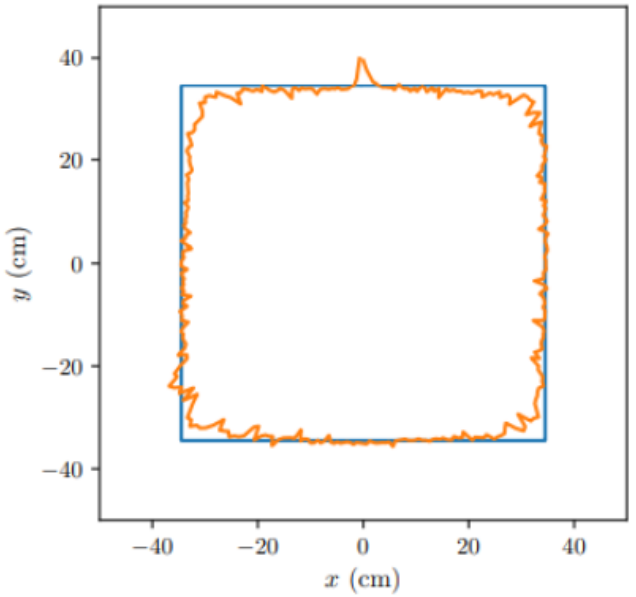


Mapping Results (Polar Plot)



Data

Angle (Degrees)	Mean	Standard Deviation
0	15mm	0.5
1	14mm	0.8
2	12mm	0.1
3	13mm	0.4



(f) Two sensors mapping a 66cm box

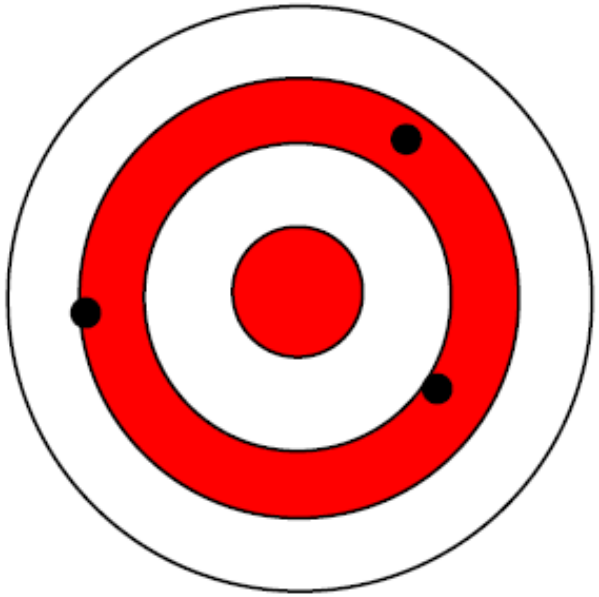
Now we can quickly assess how much the data varies.

What variance tells us will depend on what you have measured.

In this example, we ***might*** see higher variance with angles facing the robot to the corners of the environment (but this analysis wasn't included).

What do we learn…?

Data: What do we learn?



Where is the mean going to be?

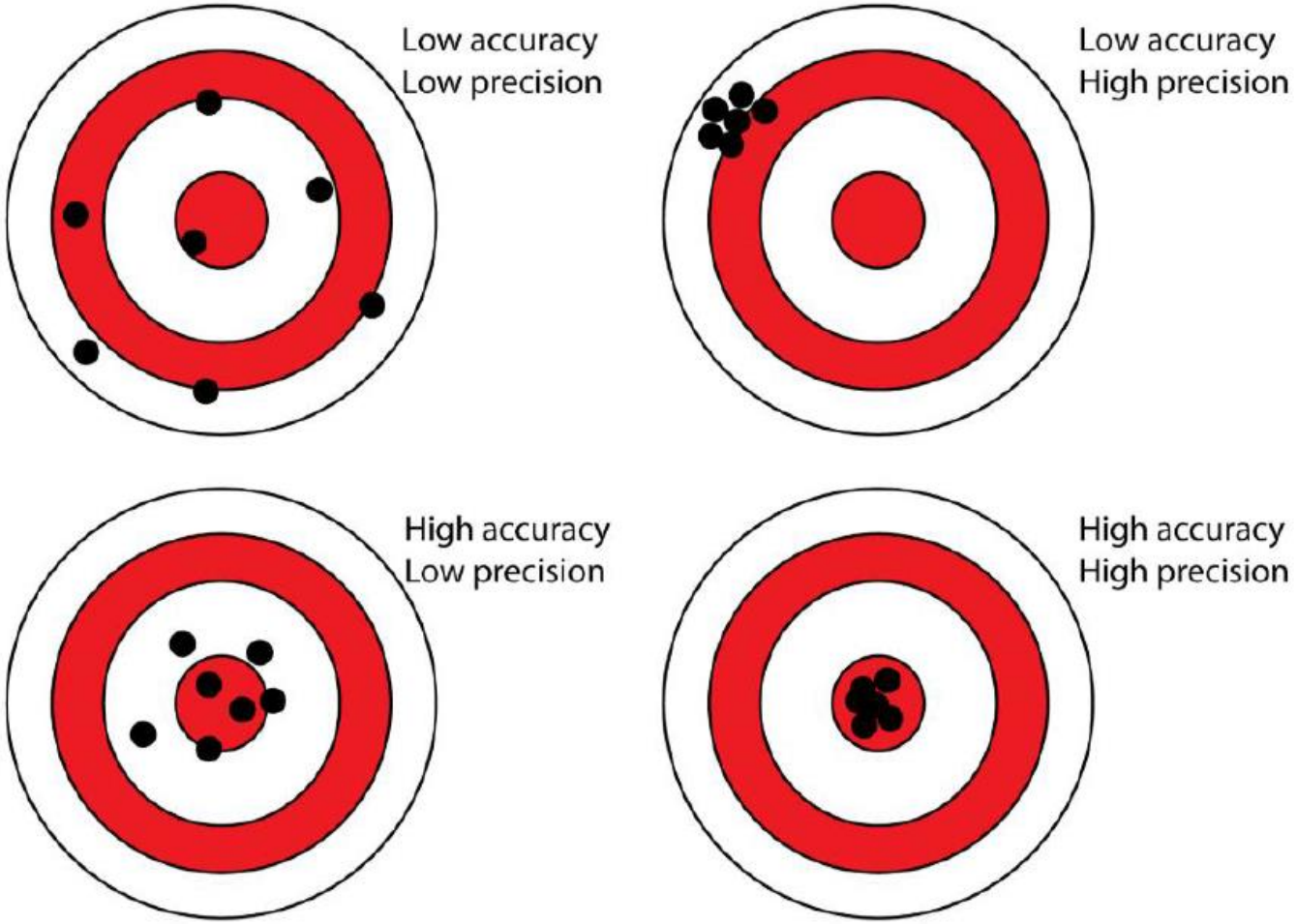
Is this a good result? (can we trust it?)

Does this tell us anything important?

Is this luck?

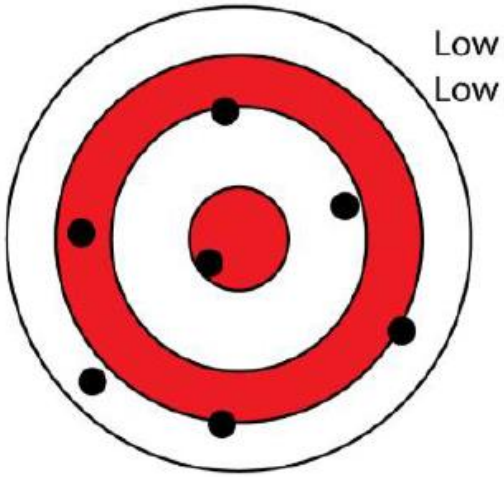
How much data should we collect..?

Data: What do we learn?



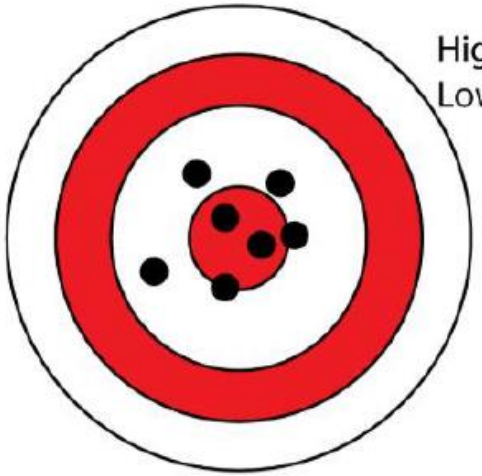
We can consider these same principles in relation to the data we collect from our experiments.

Data: What do we learn?

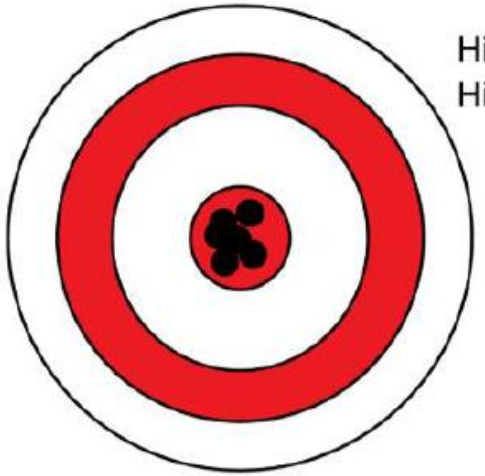


Low accuracy
Low precision

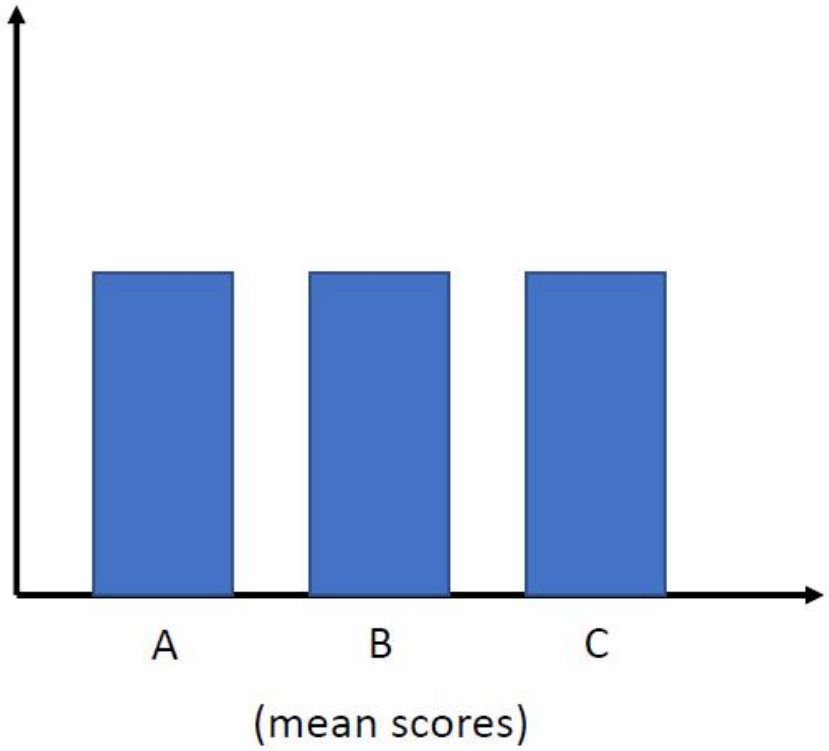
The mean of these three datasets are nearly identical, but the raw data presents different information.



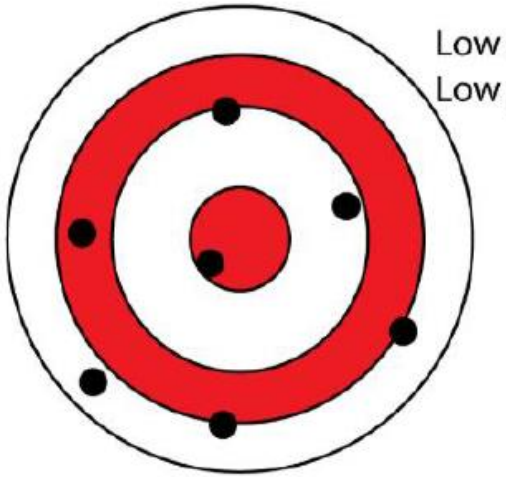
High accuracy
Low precision



High accuracy
High precision

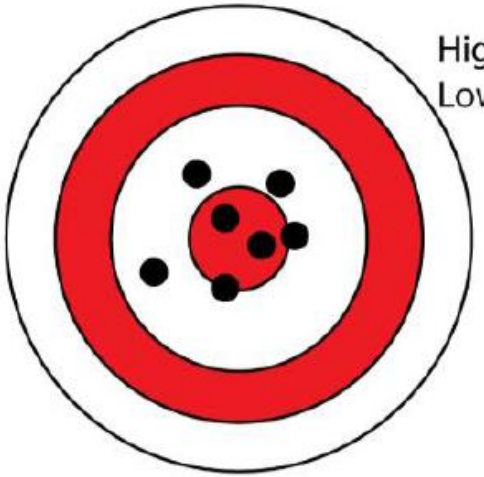


Data: What do we learn? (Error Bars)

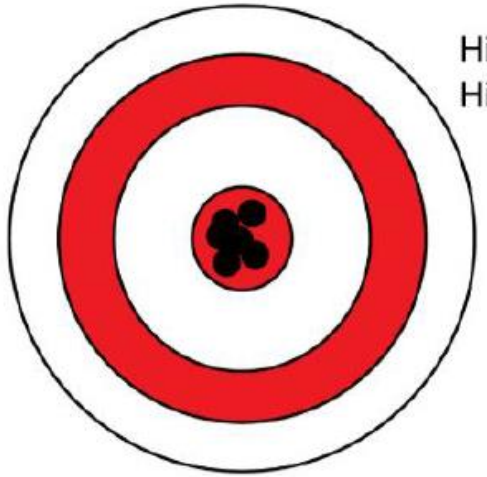


Low accuracy
Low precision

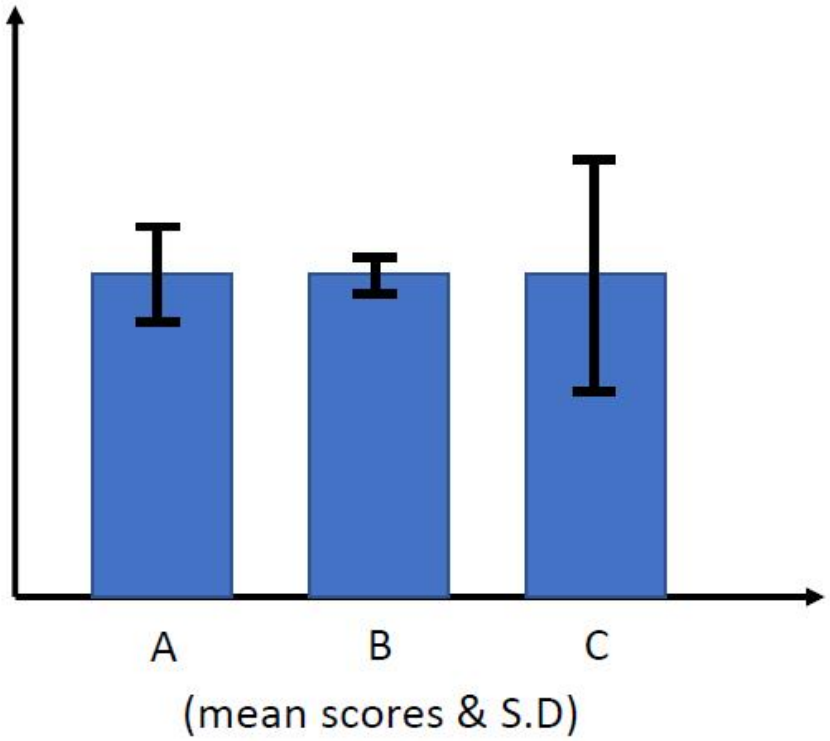
The mean of these three datasets are nearly identical, but the raw data presents different information.



High accuracy
Low precision

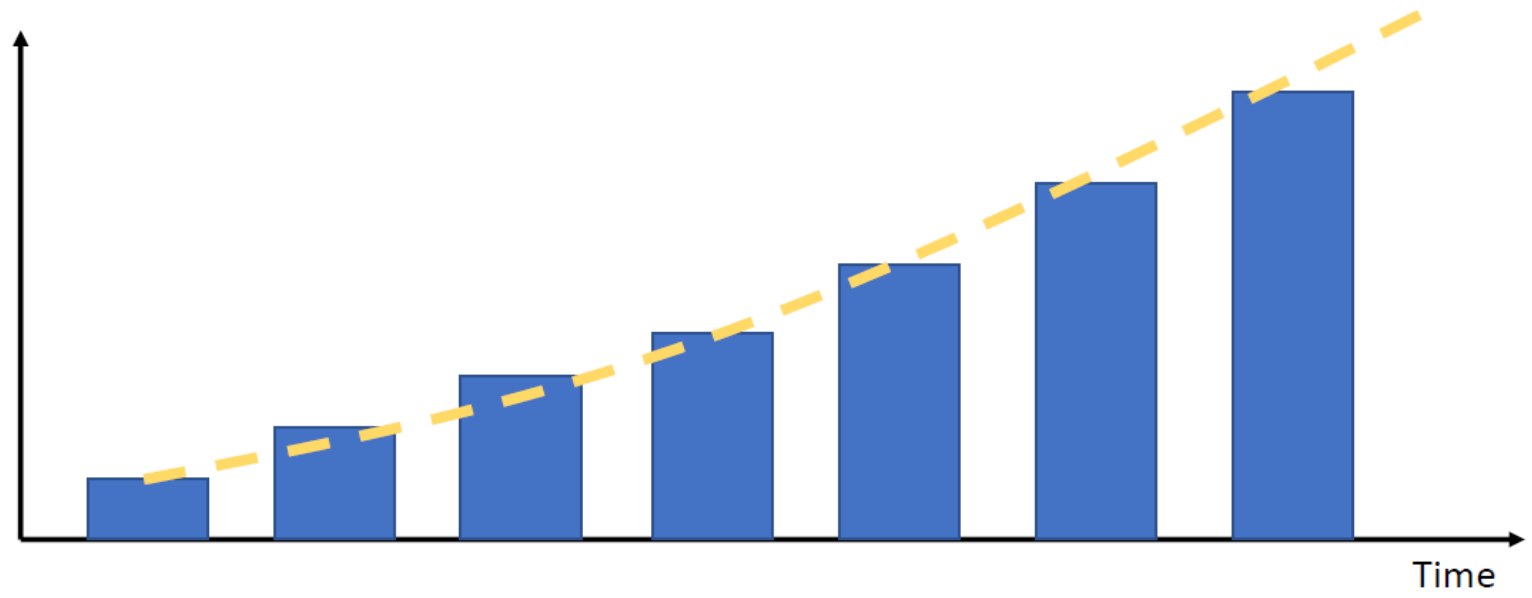


High accuracy
High precision



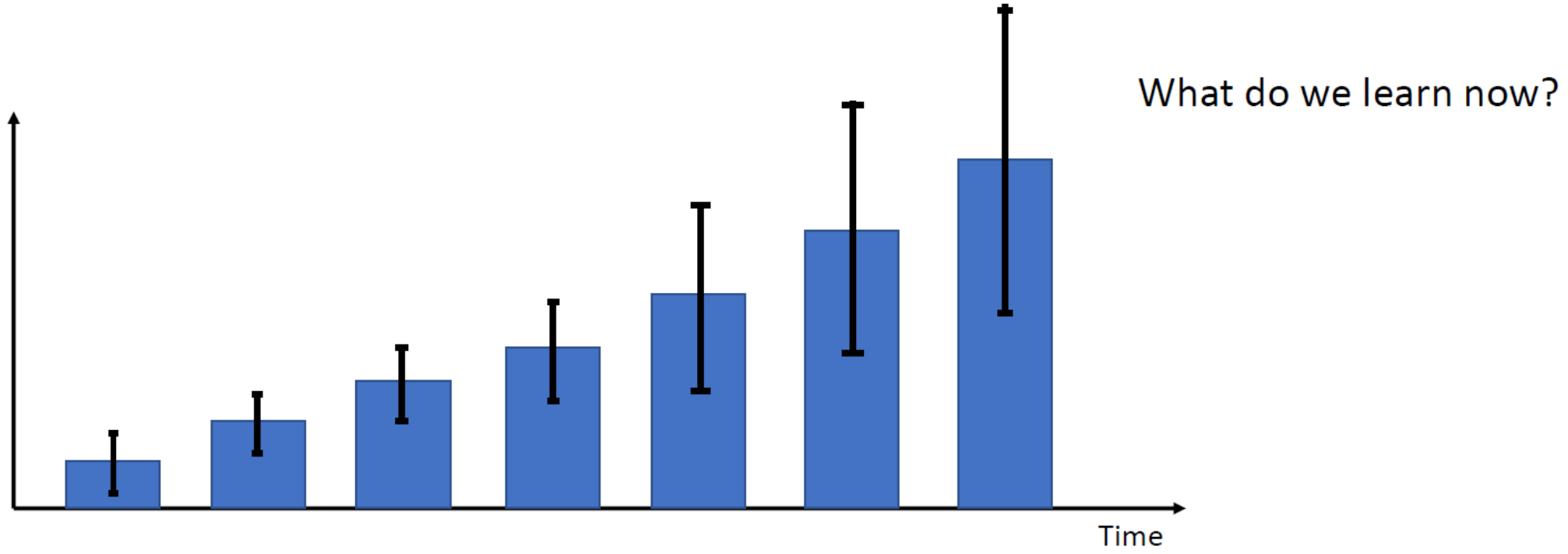
(mean scores & S.D)

Data: What do we learn? (Error Bars)



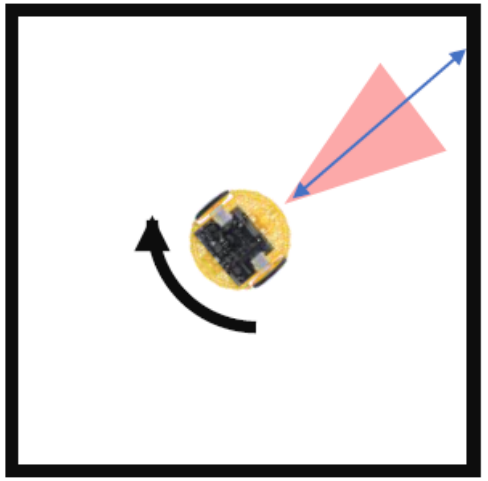
An upward trend:
A good result?

Data: What do we learn? (Error Bars)

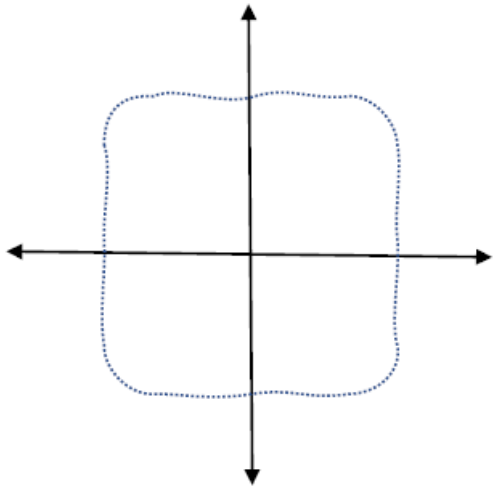


Results, Qualitative: What do we learn?

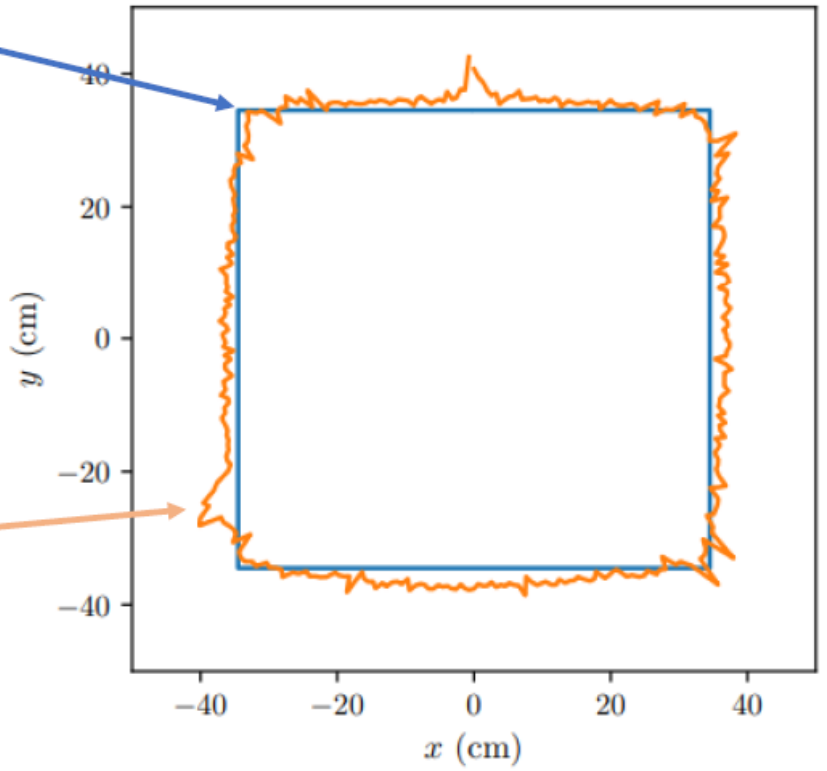
Ground Truth

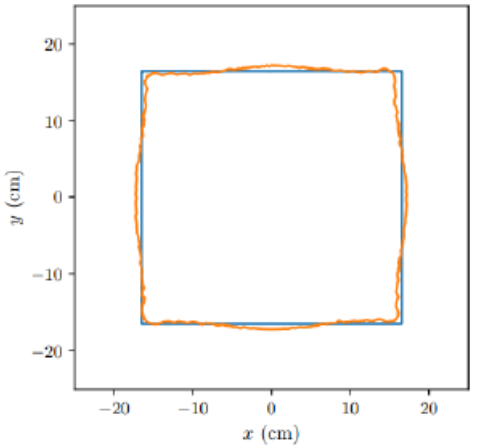


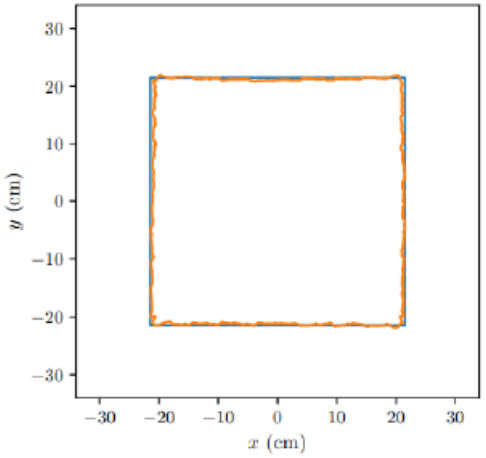
Mapping Results (Polar Plot)



Qualitative Evaluation
(an assessment of quality)

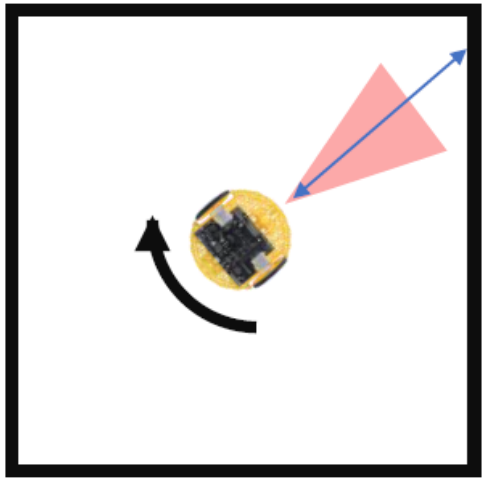




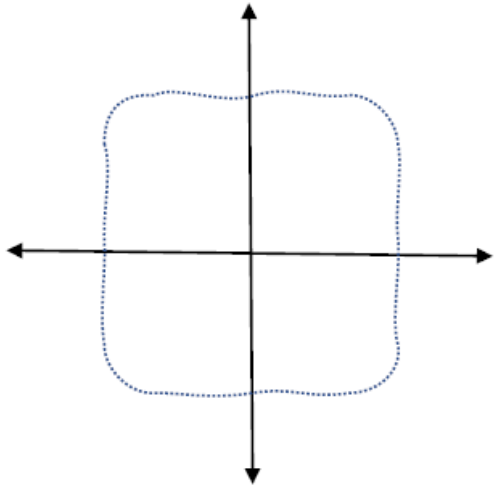


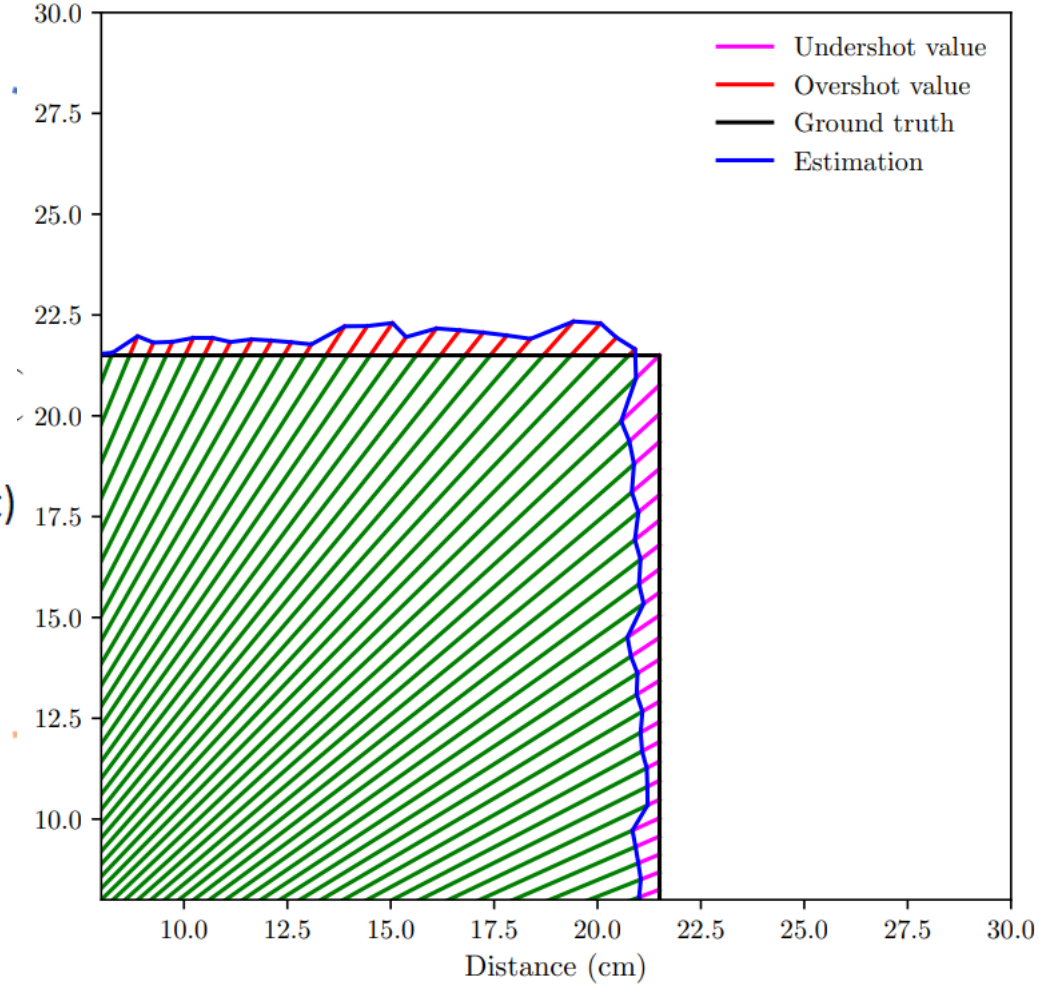
Results, Metrics (Quantitative): What do we learn?

Ground Truth



Mapping Results (Polar Plot)





Absolute Error (so +/- do not counteract):

$$E_{abs} = \frac{\sum_{t=0}^{359} |e_i - d_i|}{360}$$

Overshoot:

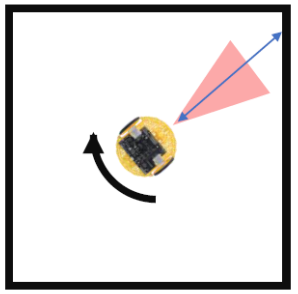
$$E_{over} = \frac{\sum_{t=0}^{359} max(e_i - d_i)}{360}$$

Undershoot:

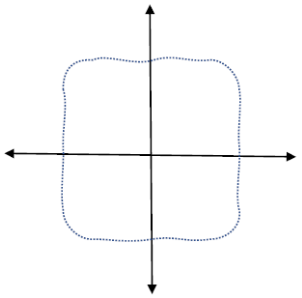
$$E_{under} = \frac{\sum_{t=0}^{359} min(e_i - d_i)}{360}$$

Results, Plots: What do we learn?

Ground Truth



Mapping Results (Polar Plot)

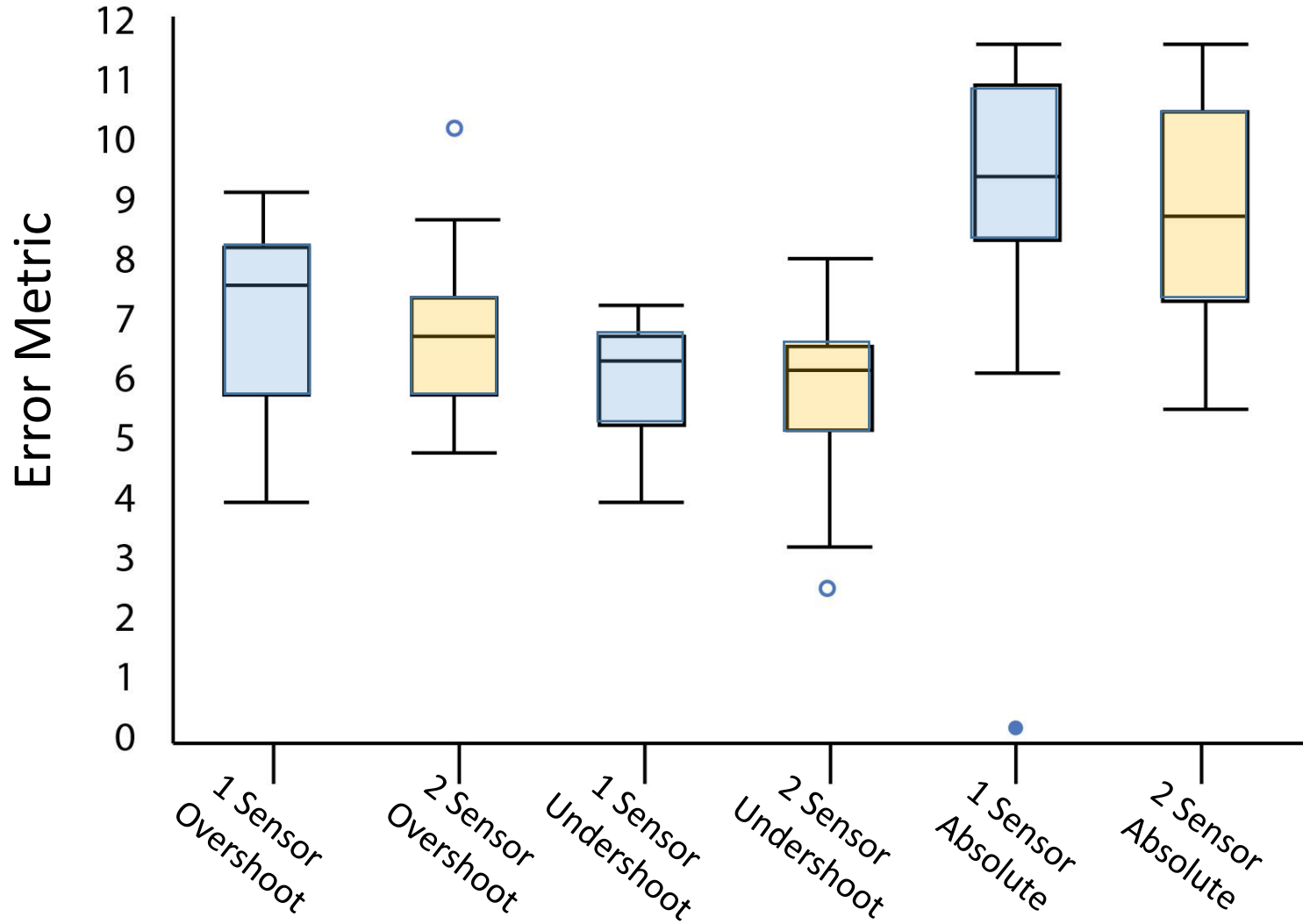


$$E_{abs} = \frac{\sum_{t=0}^{359} |e_i - d_i|}{360}$$

$$E_{over} = \frac{\sum_{t=0}^{359} max(e_i - d_i)}{360}$$

$$E_{under} = \frac{\sum_{t=0}^{359} min(e_i - d_i)}{360}$$

x10



Common Feedback

Common Feedback

1. Always label your axis, indicate units (when possible), include a legend.
    a) Remember that you can annotate plots. E.g., placing "A" on the plot, and then reference this in the body text.
2. Always caption your plots and figures.
    a) Don't rely on a caption to analyse the result. Use a caption to clarify plot construction.
3. Place your plots and figures in the document at the earliest point they are relevant.
    a) Try to avoid forcing your reader to need to constantly turn the page.
4. Always reference your figures and plots in the text **AND** discuss them explicitly.
    a) Figures and plots should be used to increase understanding and insight – so they should be a point of discussion. Not discussed, not important?
5. Never require your reader to analyse or interpret your data (you should be making a good argument).
    a) Always discuss outliers, anomalies and limitations.
6. Try to compose graphs (etc) to make comparative evaluation easier.
    1. Boxplots are great at this!
    2. You can use colour gradients on tables.
7. Avoid many separate plots, unless there is too much information.
    a) Try to keep the scale of your axis the same, when relevant.
8. Don't over-plot: the reader needs to be able to make clear observations.
9. Don't over-rely on qualitative data and/or plots.
    a) Look for a quantitative measure when possible.
    b) Using a qualitative plot: compare single examples.
10. Always include error bars or area from your dataset.
    a) If using tables, indicate variance, S.D, or other.
11. Don't use the abstract as the first paragraph of your introduction.
    a) Write your abstract last, summarise the investigation and conclusion.