Hardware Power Modeling for Turtlebot

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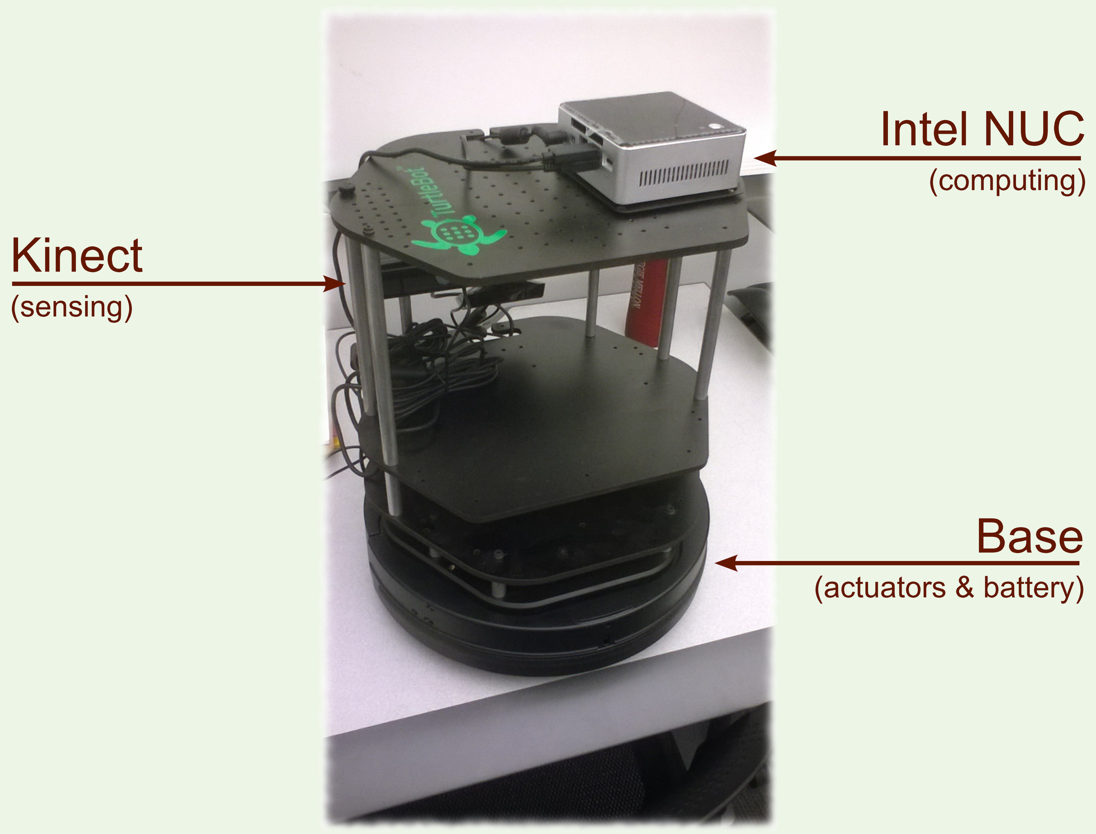
Context

- Building Resource Adaptive Software Systems (BRASS) is a project aiming to enhance *robotic adaptation* to *limited resources*.
- One such resource is battery power. Personal robots need to plan and execute adaptations to reduce power usage.
- To predict the effects of such adaptations, a *power consumption model* is needed.
- Battery power is consumed by hardware devices and software running on processing units.
- In this work we focus on *hardware power consumption* of **Turtlebot**:



Problem

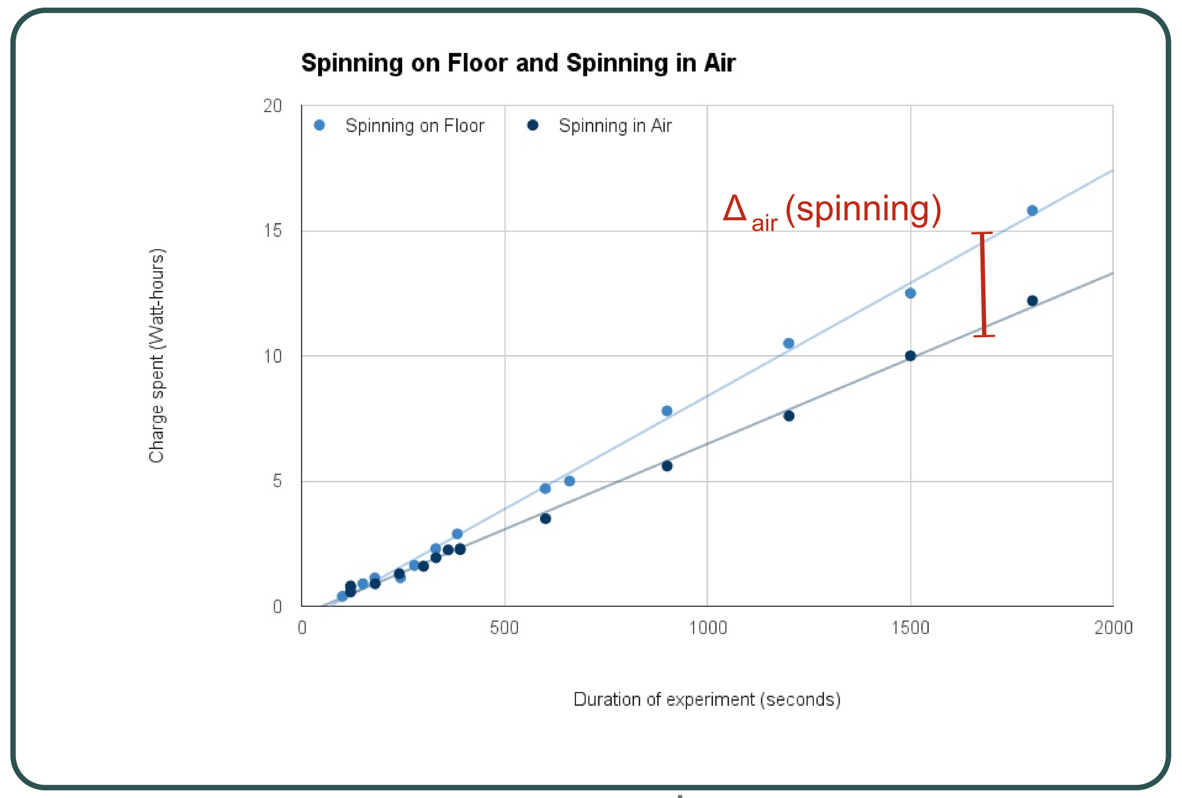
- What is the power model for the Turtlebot hardware (i.e., the base and Kinect)?
- This model should *predict the power consumption* (in watts) of the base and Kinect when performing a motion task based on variables such as speed, motion type (spinning or going forward), and the task duration.
- The model should also predict the *remaining battery charge* (in watt-hours, output voltages, and % of full charge) after completing a motion task.

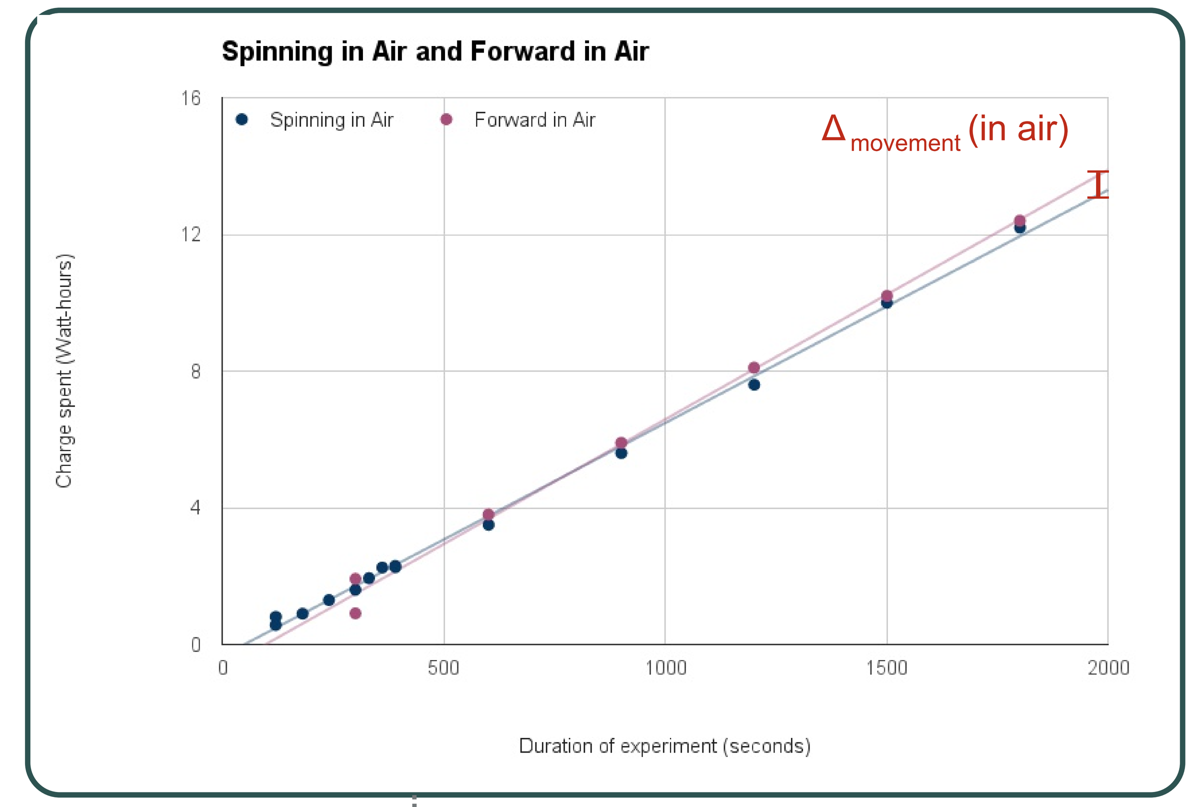
Challenges

- Direct power measurement between the motors and the battery (inside the base) is prohibitively difficult.
- Device separation is hard to achieve for longer tests. See the table below:

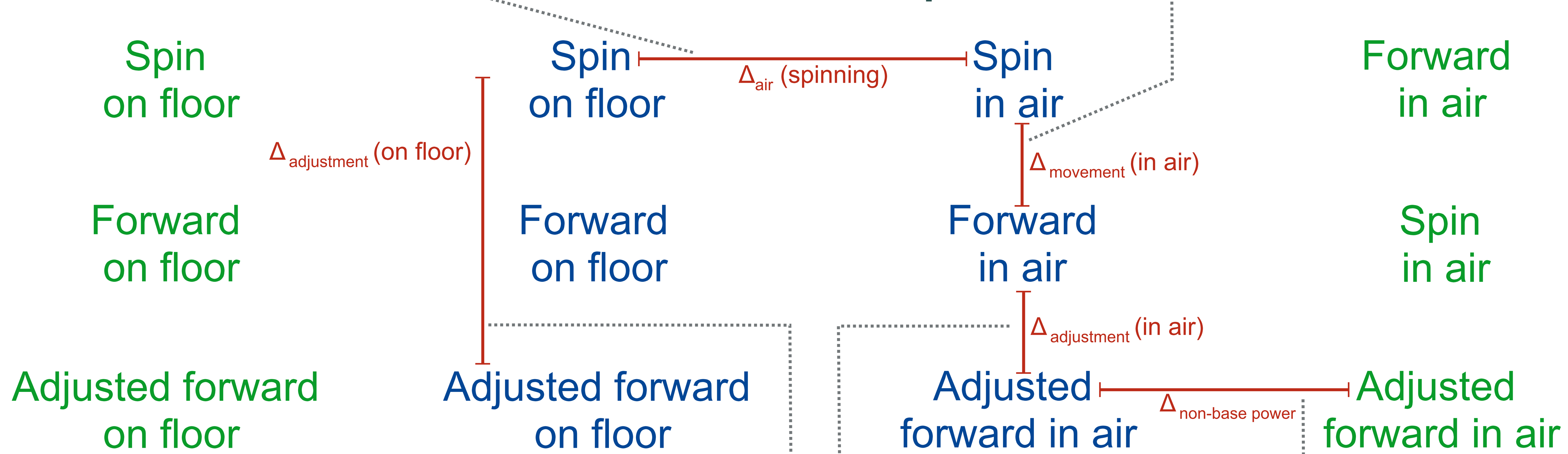
Test length

NUC plugged into base	Short (< 1 min)	Long (> 1 min)
No	Low battery consumption causes noise	Cords have a finite length
Yes	NUC power consumption causes noise	Limited controlled space



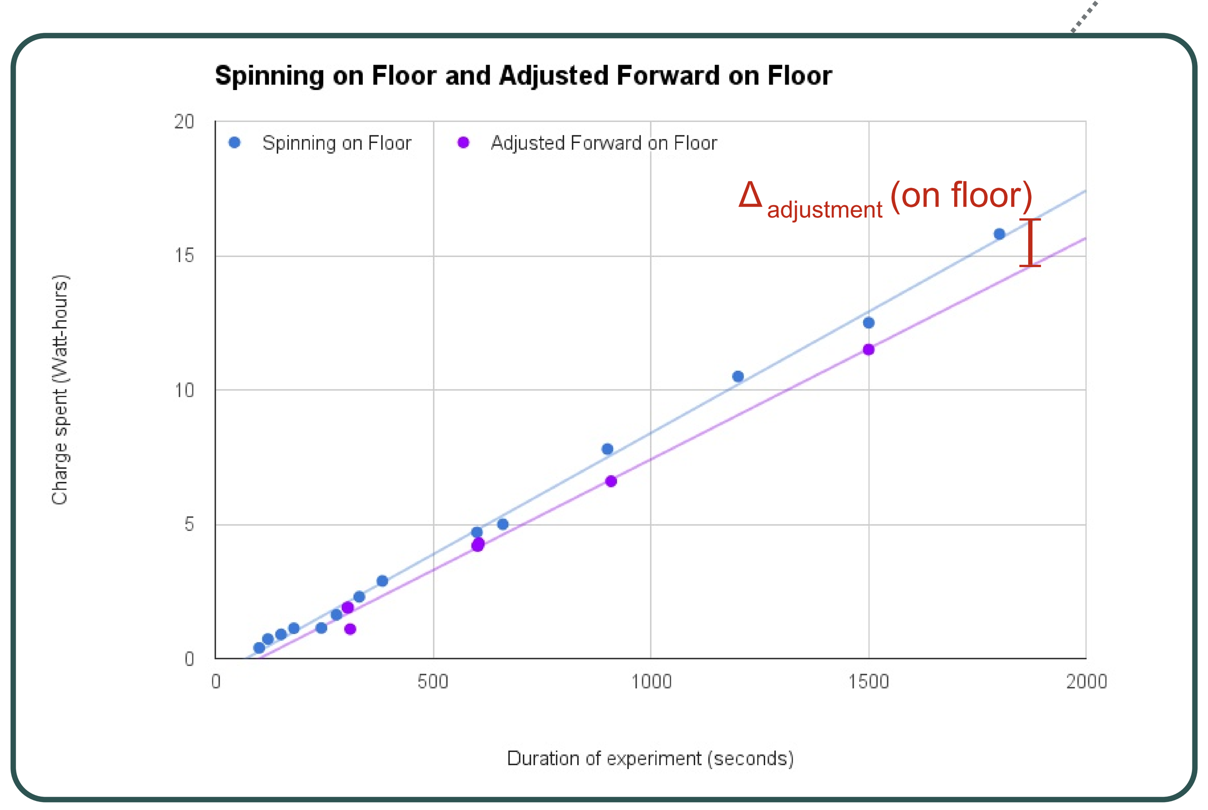


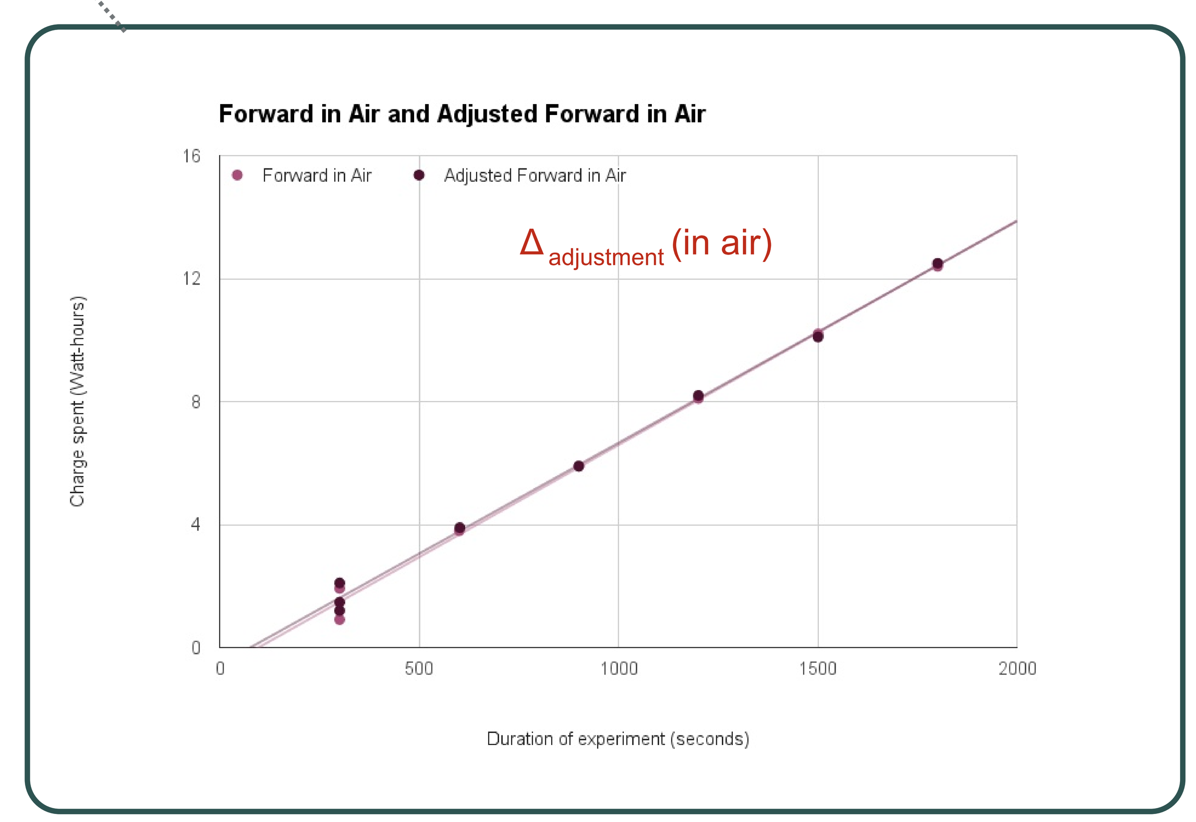
Data Collection Sequences

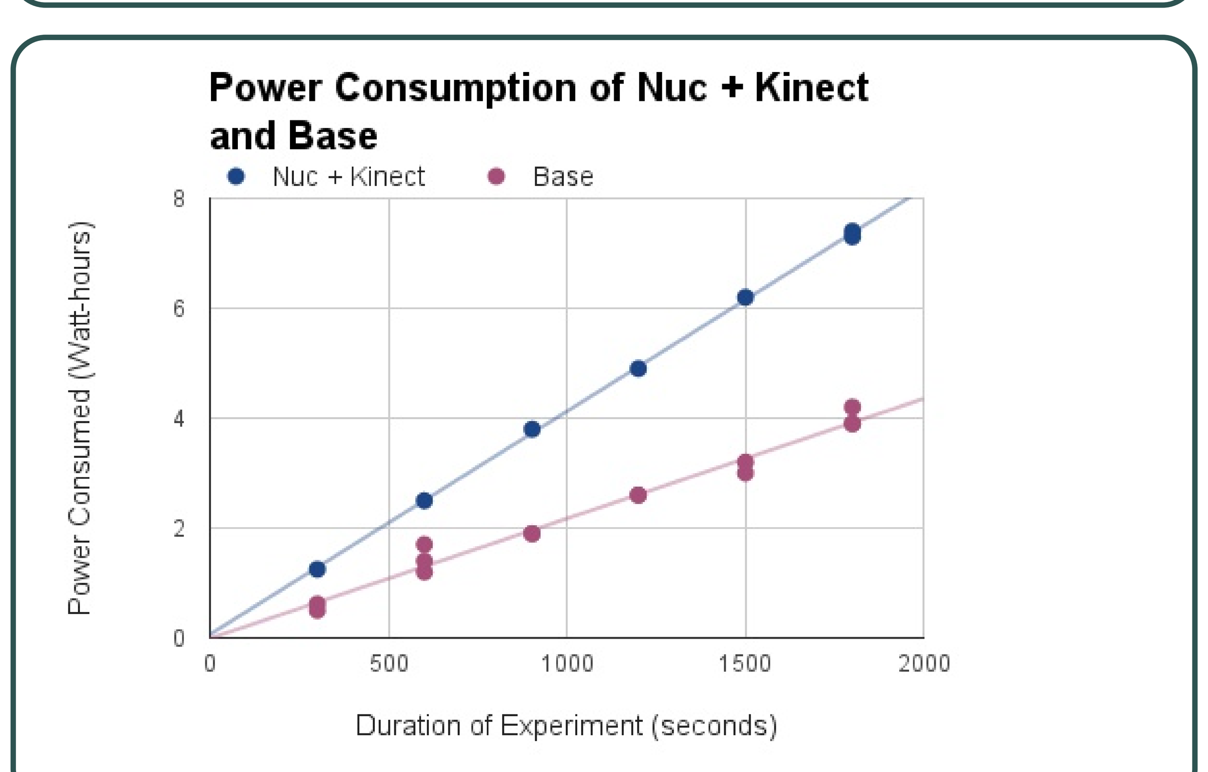


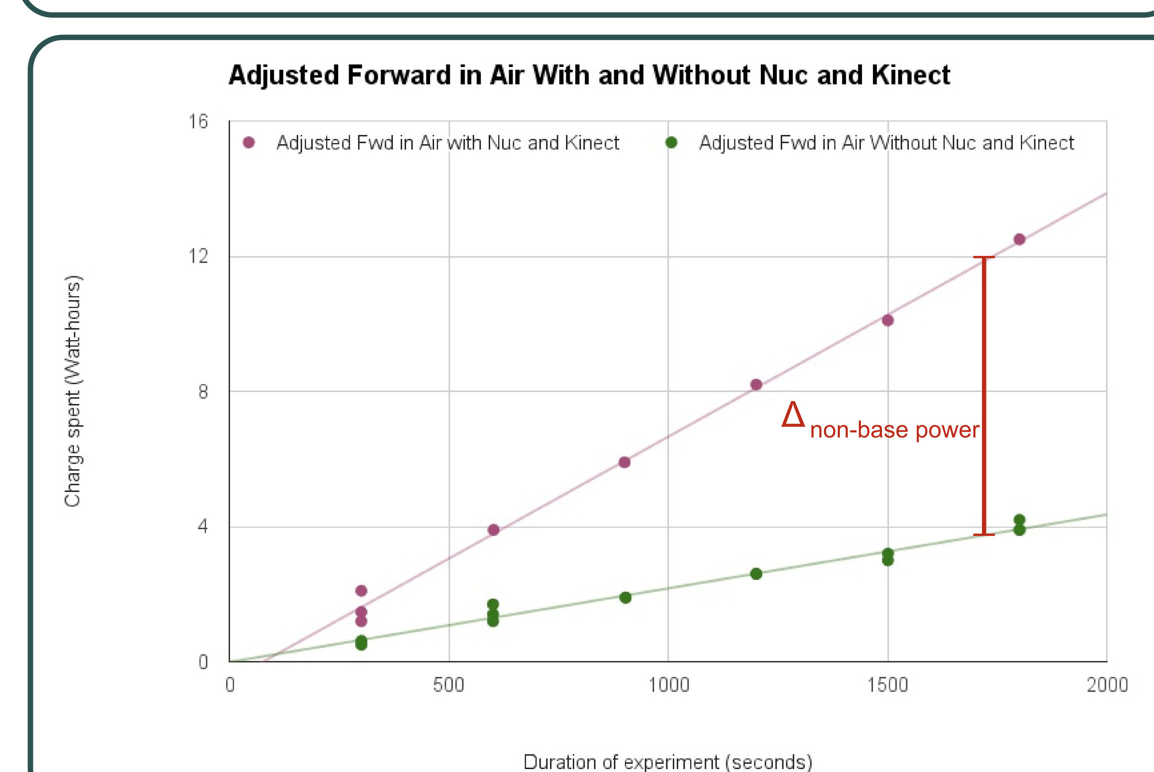
Green ~ NUC & Kinect powered externally

Blue ~ NUC & Kinect powered from the base







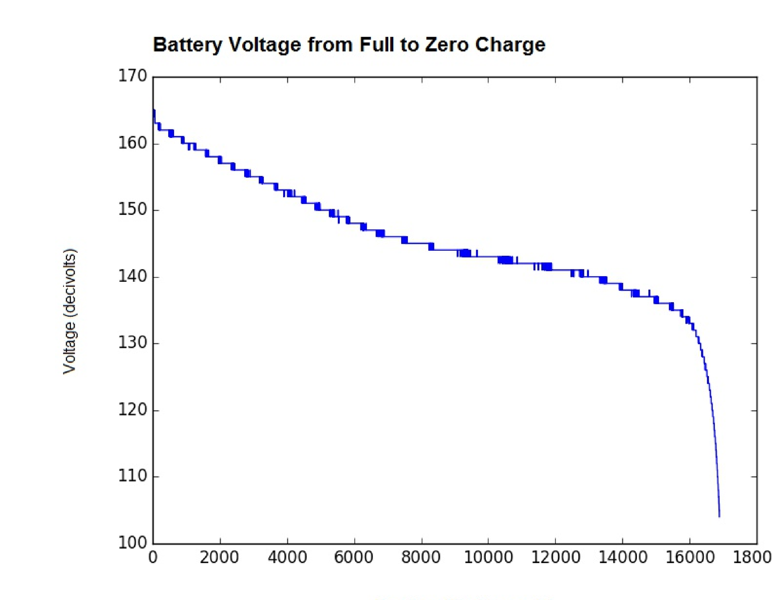


Approach

- *Experimental* data collection during motion tasks lasting for 5-30 minutes.
- *Black-box* treatment of devices: we observe only inputs and outputs.
- *Initial exploration* helped develop controlled experimental protocols.
- *Linear regression* used to create statistical models (see charts on the left).
- Variables in experiments:
  - *Independent:* time, carpet vs air, motion type.
  - *Controlled:* speed, software setup.
  - *Dependent:* battery charge/voltage, wheel clicks.

Findings

- Base & Kinect power consumption is *linear by time*. Good fit of linear regression, $r^2 \geq 0.9$.
- For spinning on the floor, the power consumption of the base in milliwatt-hours = *4.9t + 699*, with *t* being time in seconds.
- For going forward on the floor, the power consumption of the base in milliwatt-hours = *4.2t + 894*, with t being time in seconds.
- Average standard error of regression is 272 milliwatt-hours, which would translate into about 7 minutes difference per hour on average across all the data.
- Power consumption is *higher on the ground* than in the air by ~6 watts for spinning and ~3 watts for adj. forward.
- In the air, movement type is mostly insignificant: spinning and forward have about 2 minutes per hour difference.
- Battery voltage is not linear by time; see S-curve below.



Future Work

- Model validation: predicting how much power a task would use, running the task, and comparing actual power consumption with the prediction.
- Testing at different speeds and on different surfaces.
- More sophisticated motion types (e.g., arcs).
- Power simulation for a Turtlebot simulators (Gazebo).

Acknowledgments

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