IoT for Power Consumption

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Project Introduction

- Our team's objective is to design an intuitive dishwasher that can be activated via voice command through the use of an app, wireless speaker (Amazon Echo Dot), and an AI voice assistant (Amazon Alexa).
- More importantly, we want to take advantage of the fact that the price of power fluctuates throughout the day.
- Therefore, we want to predict the future price of power in order to activate the dishwasher at an optimal time to save the consumer on the operation cost of the dishwasher.

Project Solution Description

- Our solution is an IoT dishwasher that can communicate with the user using either their voice and the Echo or a mobile app. Should the user wish for it, the system is also capable of predict the best time to turn on the dishwasher and do so for the user.

Anything **+**

= AWESOME

But What is IoT?

But WHAT IS IoT (Internet of Things)?

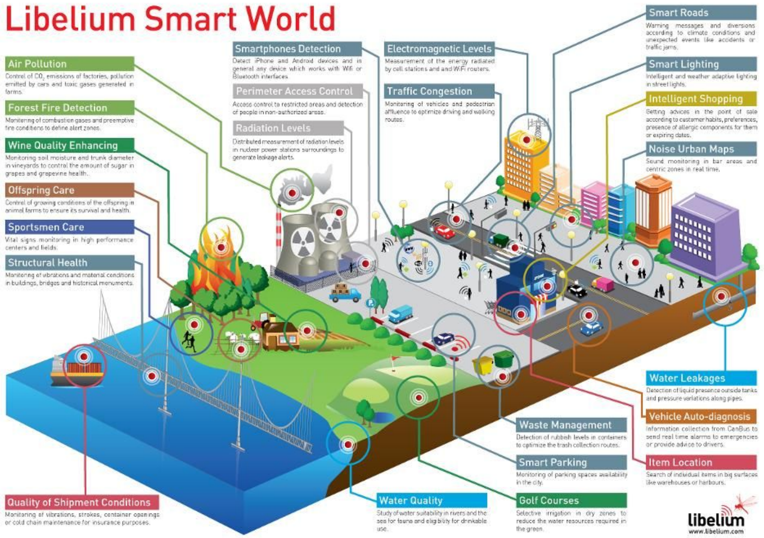
- Simply put, the concept of the Internet of Things (IoT) is all future smart devices will have the capability to connect to the Internet so they can share data with one another without requiring human-to-human interaction or human-to-machine interaction.
- “Anything that can be connected, will be connected”

But <u>WHY</u> IoT?

- The concept of IoT represents a vision where the internet extends into the real world and interacts with everyday objects. These physical items are no longer disconnected from the physical world and can be controlled remotely and act as a physical access point to the internet.
- By "digitally upgrading" everyday objects in this way enhances their physical function by also adding the capabilities of digital objects thus creating added value.

Truth is... We already utilize IoT

- Practical applications of IoT Technology can already be found in many industries today including: precision agriculture, building management, healthcare, energy, and transportation.



IoT on a Larger Scale

- Utilize IoT concept for “Smart Homes” and “Smart Cities” to reduce waste and improve efficiency on a macroscopic level.
- By having such ubiquitous computing power, it becomes possible to simultaneously keep track of building structural health, water quality, waste management, smart roads to mitigate traffic congestion, and so much more.

So where does our project fit into all this?

Societal Impact

- Individually, people would save money on their power bills by operating their dishwasher when the price of power is at the most optimal.
- From a much larger perspective, our concept of a smart dishwasher would play a great role by reducing the stress on the power grid by activating appliance during non-peak hours of power usage.
- Establish a ***“Smart Grid”*** : prevent overloading an electrical grid and prevent potential power outages, and reducing the number of hazards associated with blackouts.

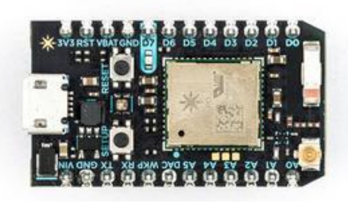
Societal Impact

- *Remember: Small things add up to become big things!*
- The success of our project would be a proof of the IoT concept that would be a catalyst to a chain reaction towards a development of a much wider variety of Wi-Fi enabled appliances that would also include: washers, dryers, heating and A/C units.

Project Components

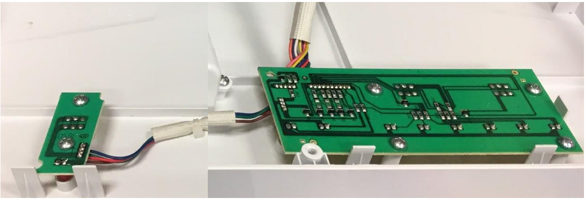
Physical Setup

0 Particle Photon



0 Relay Shield

0 Dishwasher Front Panel



Commercialization

- Device modification rather than replacement
- Can be applied to virtually any device with a switch
- Inexpensive and fast installation
- Accessible to most households with WiFi

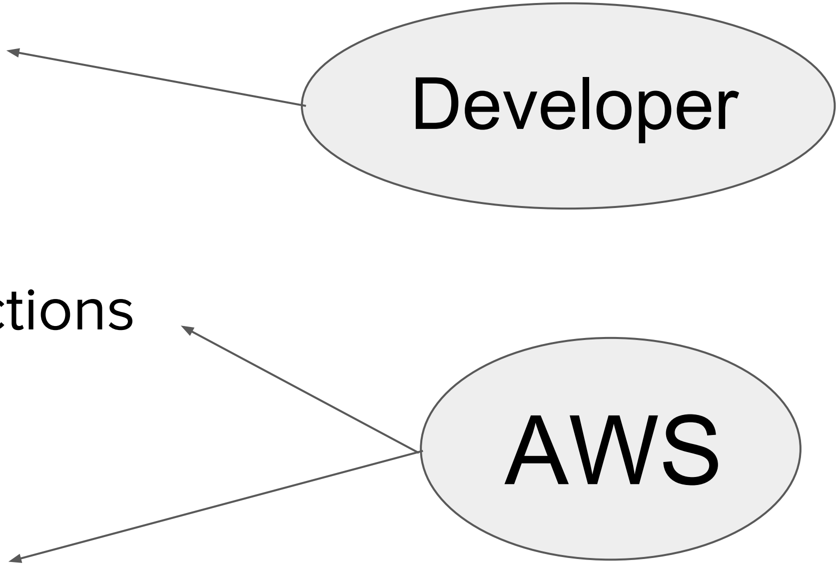
Particle Photon: $19

Relay Shield: $30

Lifetime Electricity Savings: $$$

Amazon

- Alexa Skills
  - Dishwasher
  - Server
- Lambda Functions
  - Dishwasher
  - Server
- Cloudwatch



Do Dishes Now

0 Voice

0 Alexa Skill

0 Lambda Function

0 Particle Photon

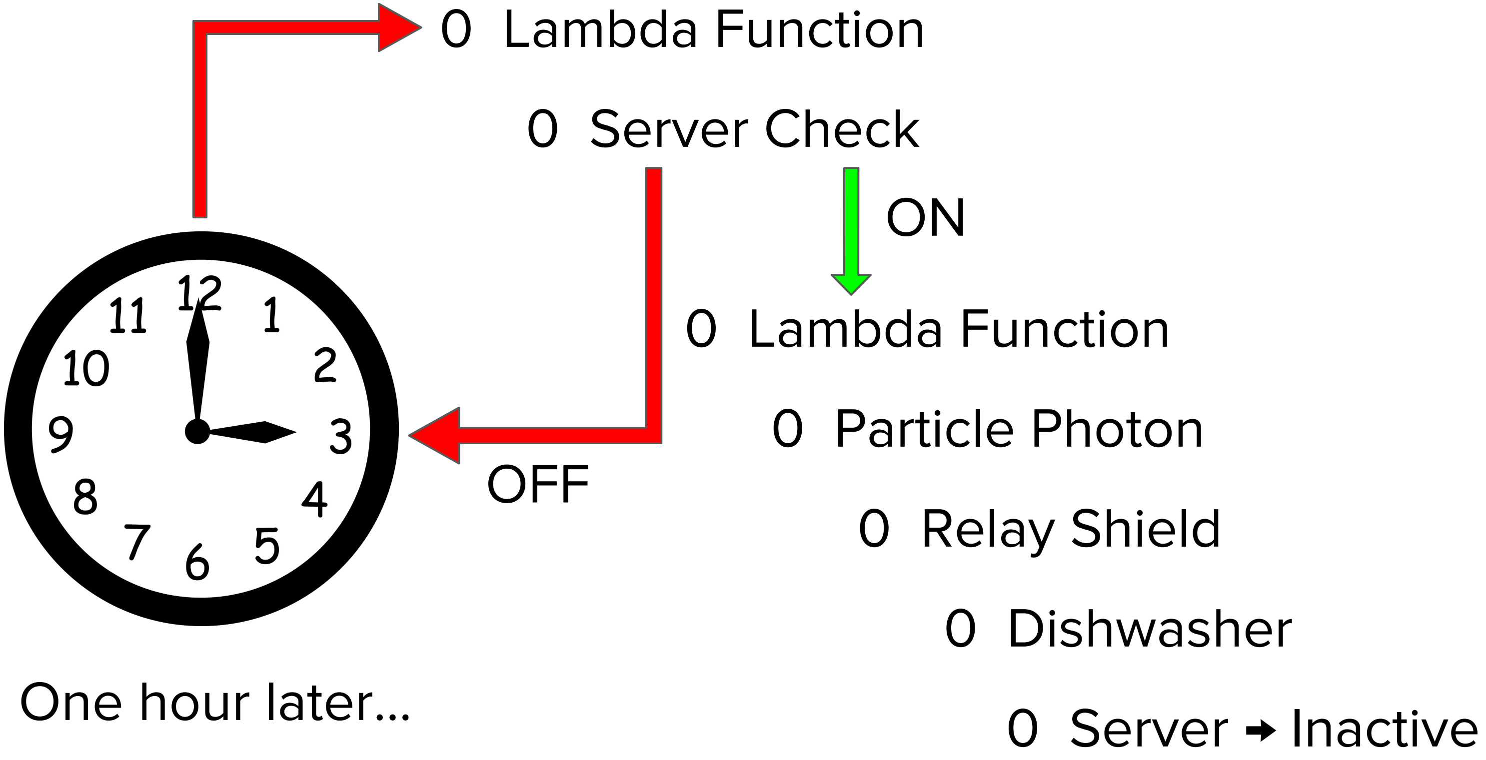
0 Relay Shield

0 Dishwasher

Do Dishes Later

- 0 Voice
  - 0 Alexa Skill
    - 0 Lambda Function
      - 0 Server ➔ Active

Cloudwatch


0 Lambda Function
0 Server Check
ON
0 Lambda Function
0 Particle Photon
0 Relay Shield
0 Dishwasher
0 Server ➔ Inactive
OFF
12 1 2 3 4 5 6 7 8 9 10 11
One hour later…

Wash Cycle

0 Normal (Default)

0 Eco

0 Rinse

0 Rapid

0 3 in 1

0 Intensive

Price Modeling

Motivation

- With the advent of battery storage systems, the nature of energy usage is undergoing serious changes.

- Idea of smart homes and cities encourages to **optimize power consumption**.

- We are working with prices of Commonwealth Edison (**ComEd**) in Illinois.

Negative Prices

- Happens when electricity supply is greater than the demand.

- Customers are actually being **paid to use electricity** during negative priced hours.

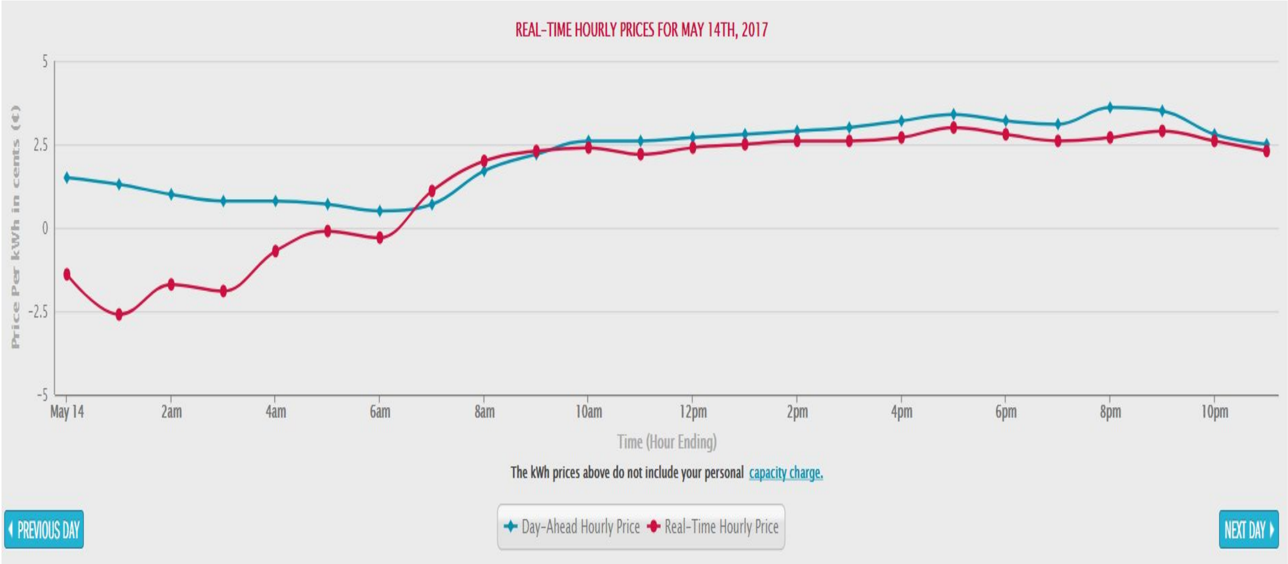


Fig 1: Negative Prices observed May 14, 2017

Setup

- Real time spot prices available at https://hourlypricing.comed.com/live-prices/ - 5 minute.
- We plan on turning the dishwasher on between **11 PM tonight and 5 AM tomorrow morning**.
- Retroactive average as follows:

$$R_t = \frac{1}{12}\sum_{i=0}^{11} P_{t-5i}$$

to compute the charges for any usage in the time interval (t-60, t].

Initial Algorithm

Coarse Regression:

Mean of previous day's prices to predict current day's prices

Improved regression:

Regress on the historical averages of the price and the prior price 5 minutes back.

- **Good Day**

Error in predicted prices through improved regression is below a threshold

- **Bad Day**

Error in predicted prices through coarse regression is low.

- To distinguish between good and bad days:

Use absolute difference between the prices of first two time slots i.e. 11 PM and 12 AM, and conclude it as a good day if the difference is below a threshold.

Regression

To capture seasonality, historical averages is used for the past N_H days.

$$H_t = \frac{1}{N_H} \sum_{i=0}^{N_H} P_{t-1440i}$$ where we have 1440 minutes in an hour.

We fit the regression model on prior prices and historical averages as follows:

$$P_t = \alpha P_{t-5} + \beta H_t + c + \varepsilon_t$$

where ε_t denotes an i.i.d. collection of zero mean random variables.

Minimize the residual sum of square errors as follows:

$$(\alpha, \beta, c) = argmin \{\sum_{t\ admissible} |P_t - (\alpha P_{t-5} + \beta H_t + c)|^2 : (\alpha, \beta, c) \epsilon R^3 \}$$

Design matrix A, columns of which are given by:

$$A_1 = P_{t-5}$$
$$A_2 = H_t$$
$$A_3 = 1$$

and the response variable $y = P_t$:

$$(\alpha, \beta, c) = (A^T A)^{-1} A^T y$$

Statistical Analysis of errors

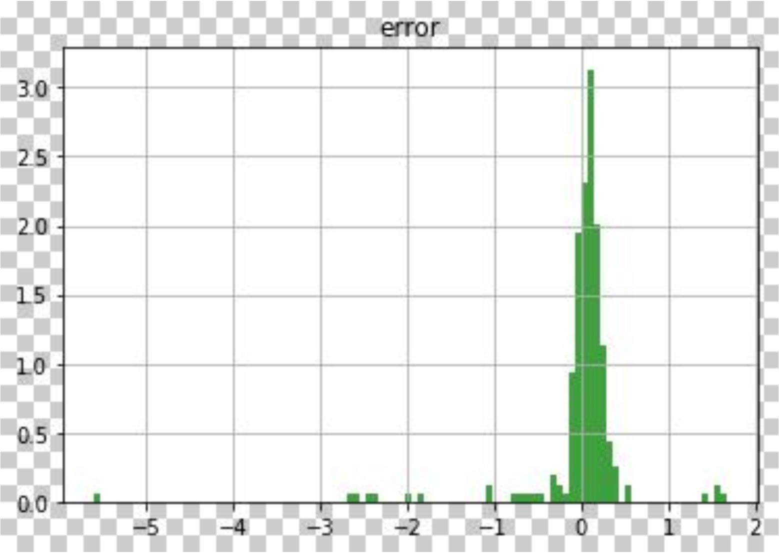


Fig : Histogram for the errors on regressed prices

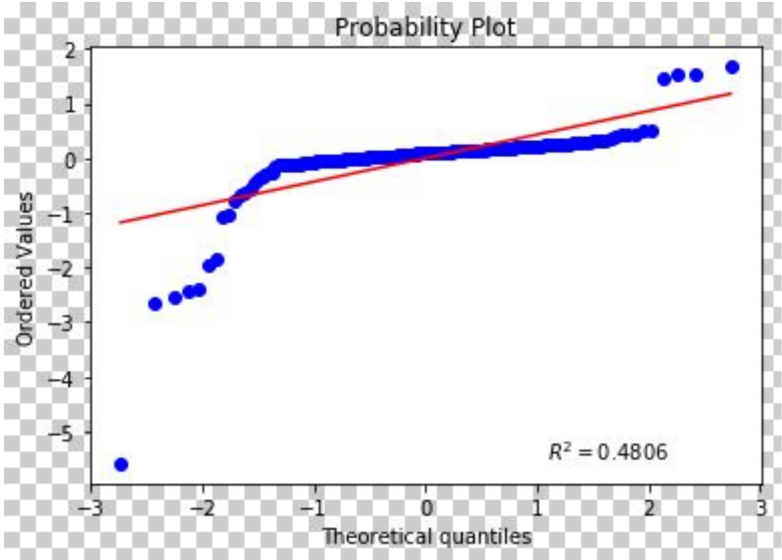


Fig : QQ plot for the errors on the regressed prices indicating heavy tail

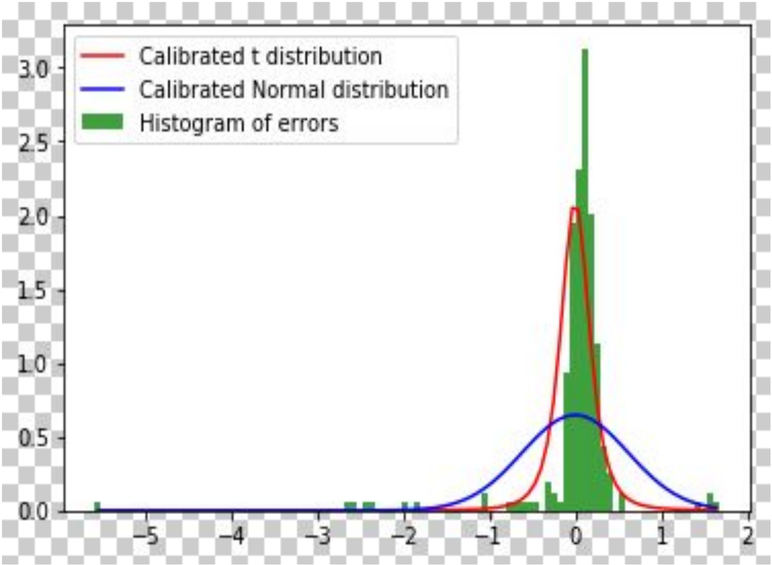


Fig: Calibrated t-distribution to the errors

Optimal Stopping Policy

If the electrical appliance runs for $T_{runtime}$ minutes, then the most information will be available at

$$n_{mi} = 5\left(ceil\left(\frac{60 - T_{runtime}}{5}\right) - 1\right) minutes$$

- Either turn the appliance on at the current hour based or wait until the next hour with cost V.

- The optimal time to switch on the appliance is:

$$t^* = min\,\{t_n \colon n \in \{0,1,2,3,4,5\} : R_{t_n} < V(t_n)\,\}$$

Exercise Price

The exercise price R_t at the current hour t is computed as follows:

$$R_{t_n} = \frac{1}{12}\sum_{n'=1}^{n_{mi}} P_{t_n+5n'} + \frac{1}{12}\sum_{n'=n_{mi}+1}^{12} E(R_{t_n+5n'})$$

Continuation Price

Value at the decision time t_n is given by:

$$\mathrm{V}\,(\boldsymbol{t}_n) = \boldsymbol{E}(\boldsymbol{R}_{\boldsymbol{t}_n+1} \wedge \boldsymbol{V}(\boldsymbol{t}_{n+1}))$$

We define the value at the terminal node as ∞

$$\mathbf{V}(\boldsymbol{t_5}) = \infty$$

This means that infinite cost is incurred if the appliance is not turned on at the last hour.

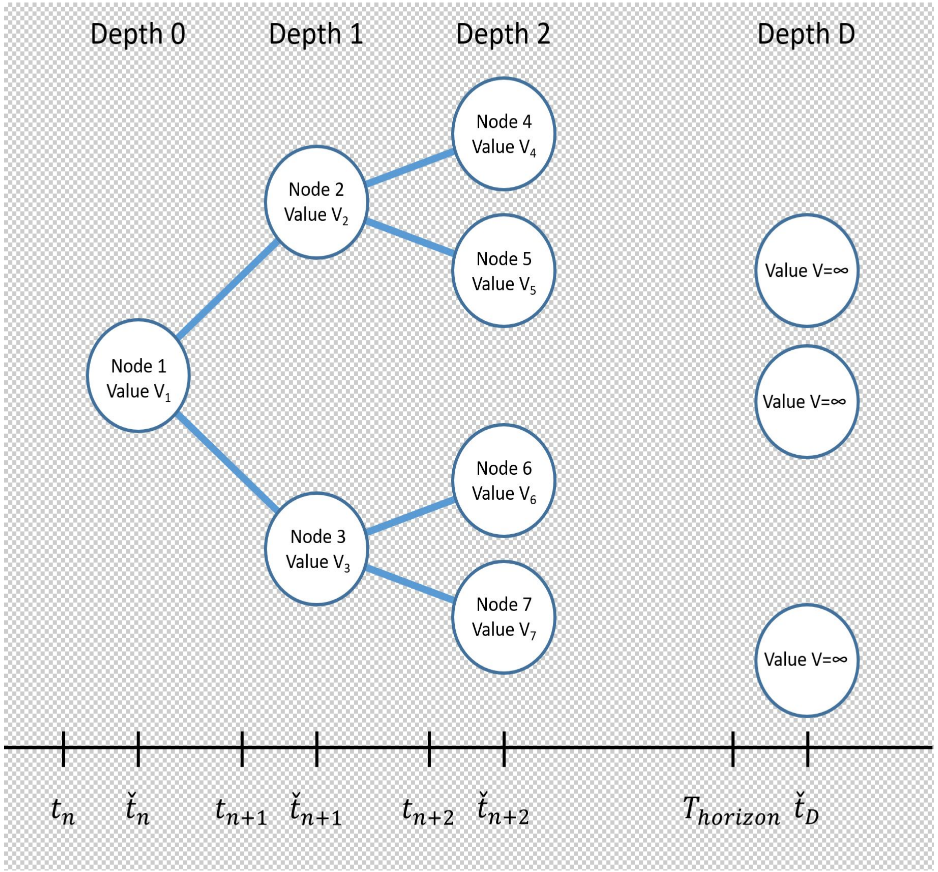


Fig: Tree created in forward direction but evaluated backwards for computing the optimal policy

The states of P_{t_n} can be isolated and the effects of historical prices and noises can be precomputed.

Future Directions

- Using the historical averages from past 5 Wednesdays to predict the price on Wednesday

- Comed also provides the prediction of day ahead prices, we wish to regress on them as well while modeling the prices.

Credits and Contributions

Credit to the following individuals outside of the 2017 Mottier Innovation Challenge project for their contributions throughout the lifetime of the project includes:

- Professor Richard B. Sowers (ISE Department)
- Professor Ramavarapu S. Sreenivas (ISE Department)
- Daniel J. Block (Engineering Teaching Lab Specialist) (ECE Department)
- Rachel Zilz (Undergraduate, ISE Department)

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- Professor Richard B. Sowers (ISE Department)
- Professor Ramavarapu S. Sreenivas (ISE Department)

Technical expertise and advice received from:

- Daniel J. Block (Engineering Teaching Lab Specialist) (ECE Department)

Current project expands upon original work from Spring 2017 REU:

- Rachel Zilz (Undergraduate, ISE Department)