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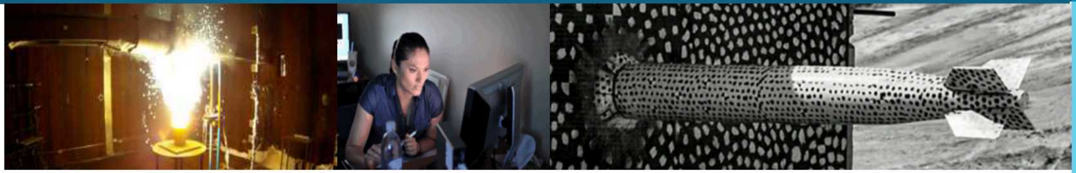
Task-Specific Compressive Optical System Design through Genetic Algorithms



PRESENTED BY

Meghan Galiardi

Tu-Thach Quach, Gabriel C. Birch, Charles F. LaCasse, and Amber L. Dagel

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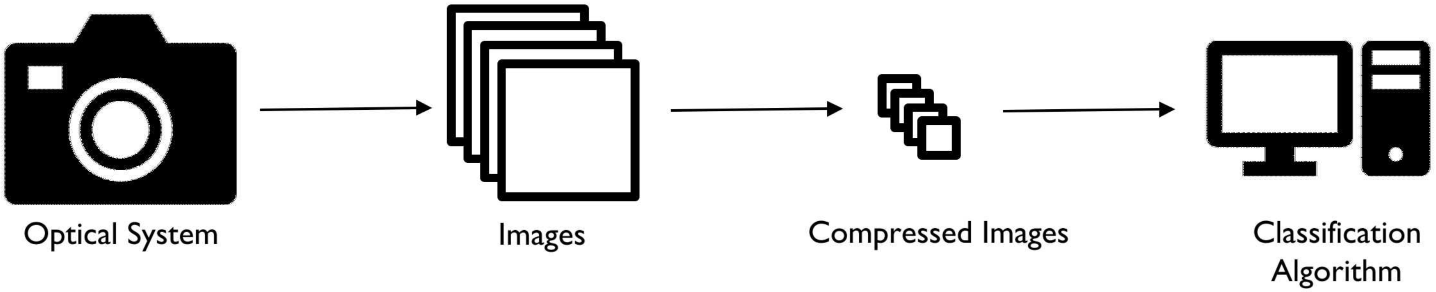
Outline

- Task-Specific Sensing
- Previous Work
- Our Approach
- Simulation Results
- Future Work

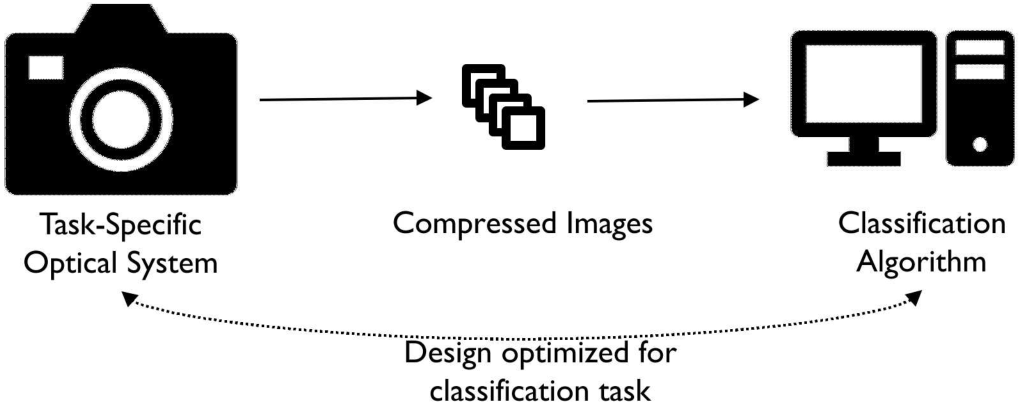
Compressive Classification



- Optical system and algorithmic classification design process is linear, one-directional
- Current ML and DL methods for target classification typically rely upon algorithms applied to data measured by traditional imagers
- This design paradigm fails to enable the ML and DL algorithms to influence the sensing device itself, and treats the optimization of the sensor and algorithm as separate sequential elements.

Can we create a holistic design of computational imaging systems optimized for specific classification tasks?

Task-Specific Sensing



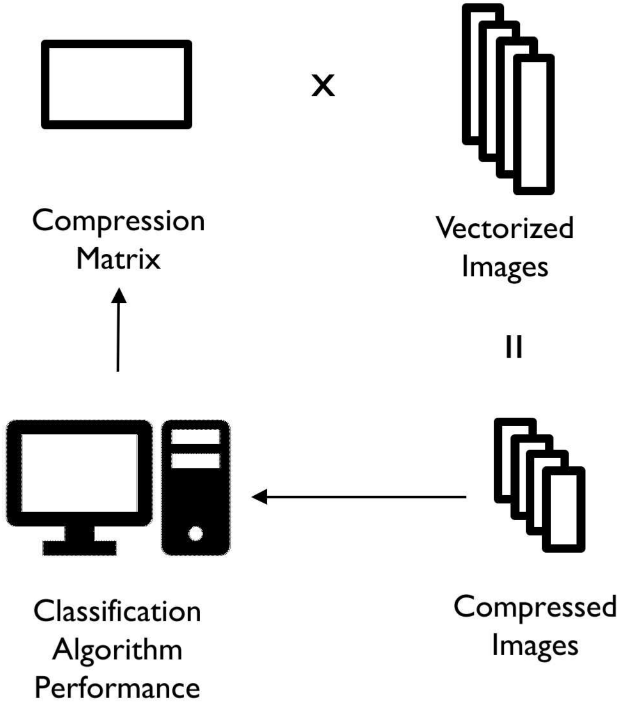
- Non-traditional optical system designed for specific target classification
- Inexpensive to manufacture
- Reduced storage and bandwidth requirements
- SWaP

How do we use ML and optimization to determine **optimal representations** for compressive classification that can be **physically realized** in hardware?

Conceptual Approach

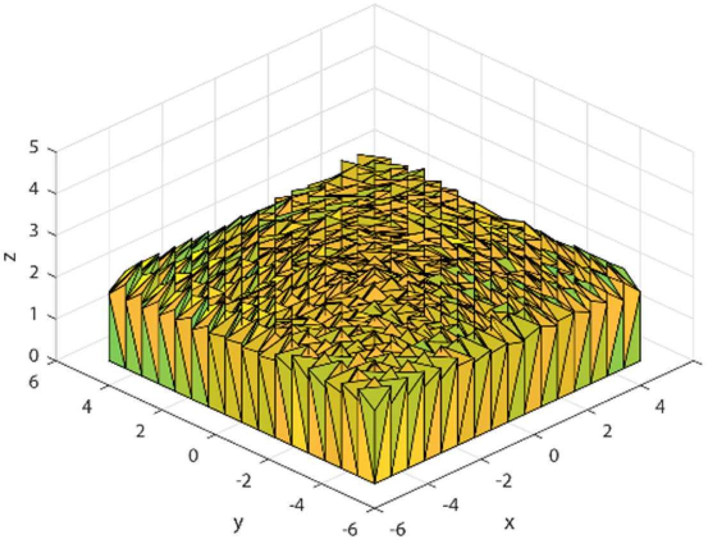
Algorithmic

Identify optimal compression matrix which produces best classification performance



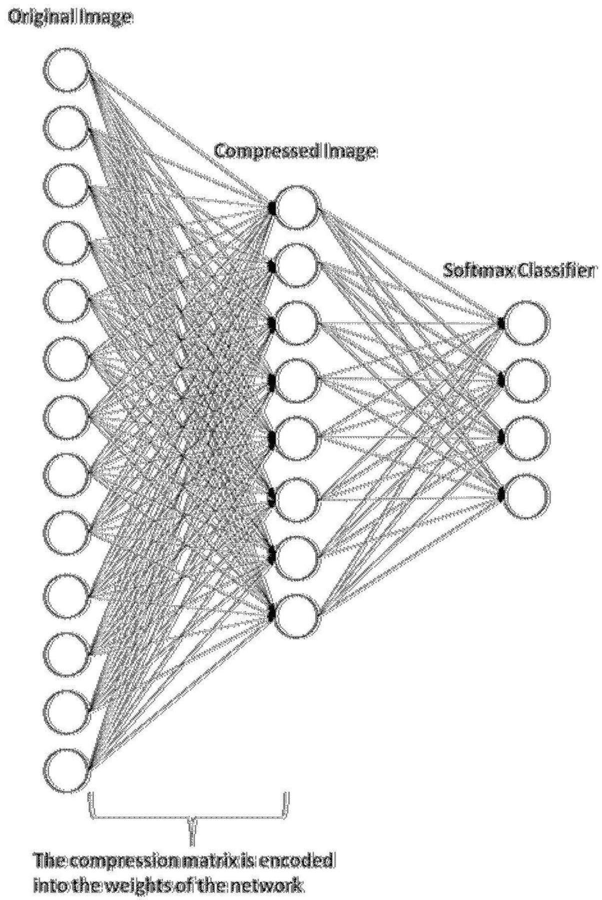
Hardware

Create an imaging device that maps object space to image space based on the optimized compression matrix determined by algorithmic approach



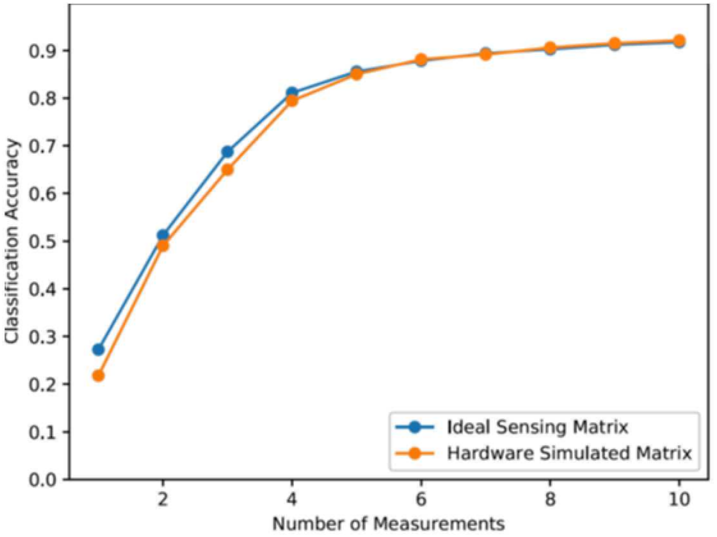
Previous Approaches

Algorithmic – Neural Network



$$\underset{A,\theta}{\text{minimize}} \quad \lambda||A||_1 - \sum_{x\in\mathcal{X}}\sum_{c\in\mathcal{C}}[c = c_x]\log p_\theta(c|Ax)$$

Hardware – Refractive Prism Array



Birch, Gabriel C., Tu-Thach Quach, Meghan Galiardi, Charles F. LaCasse, and Amber L. Dagel. "Optical systems for task-specific compressive classification." In *Optics and Photonics for Information Processing XII*, vol. 10751, p. 1075108. International Society for Optics and Photonics, 2018.

Practical Implementation Difficulties

- Difficulty 1 - Every non-zero element within the compression matrix must be realized by a prism and filter pair.
- Solution 1 - Enforce sparsity constraint on compression matrix.

- Difficulty 2 - Positive and negative values requires dual optical paths.
- Solution 2 – Enforce non-negative constraint on compression matrix

- Difficulty 3 - Wide variety of values within an optimized compression matrix require a set of custom designed filters for each prism component in an array.
- Solution 3 - Restrict values of compression matrix to a set of predefined discrete transmission values.

Solution 3 requires an algorithmic approach other than the neural network approach.

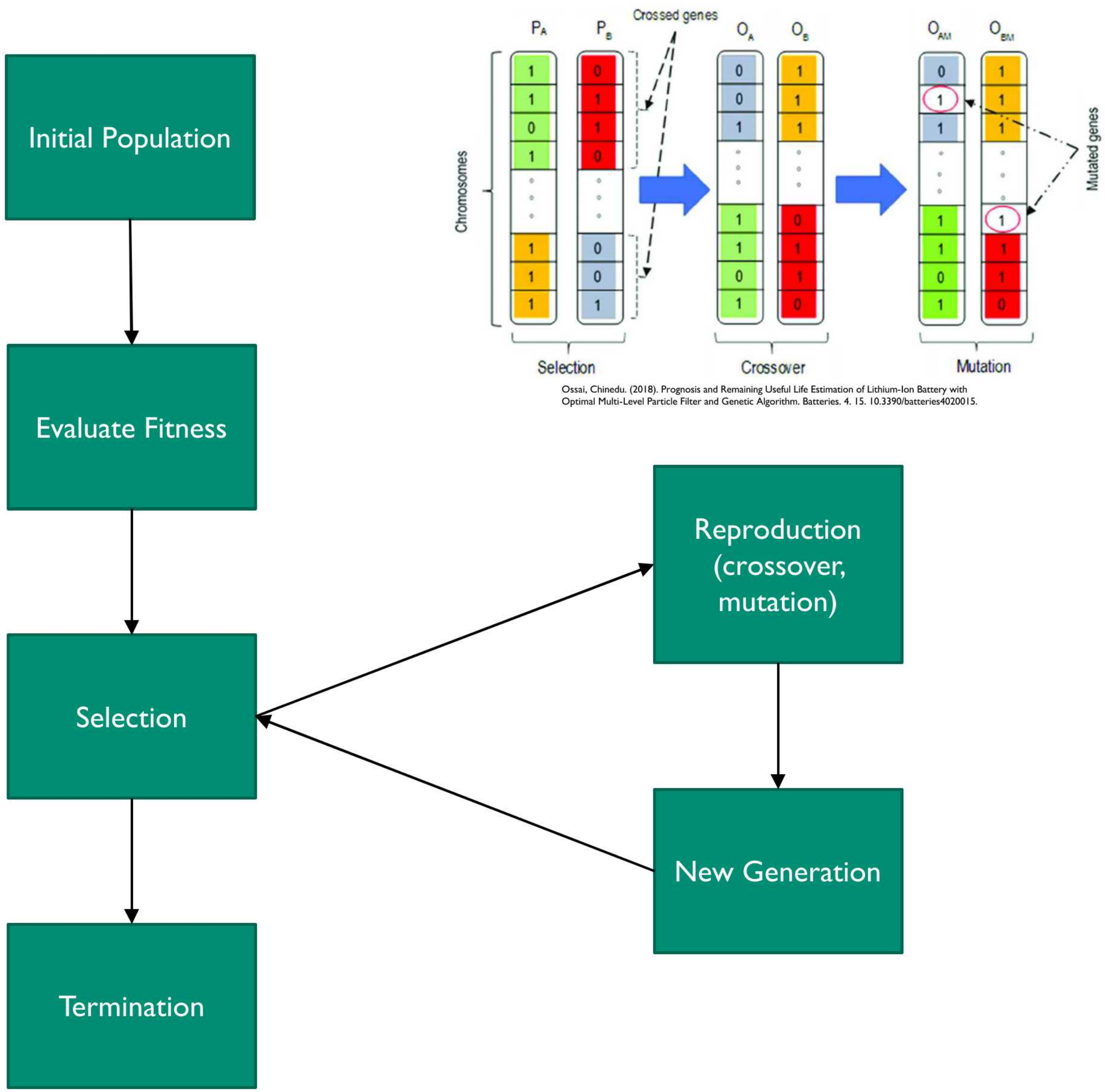
Approaches Considered

$$\max_{A,\theta} \sum_{x \in X} \sum_{c \in C} [c = c_x] \log p\_\theta(c|Ax)$$
$$\text{s.t. } A_{ij} \in B$$

Optimization problem is high-dimensional, expensive, and black-box (HEB)

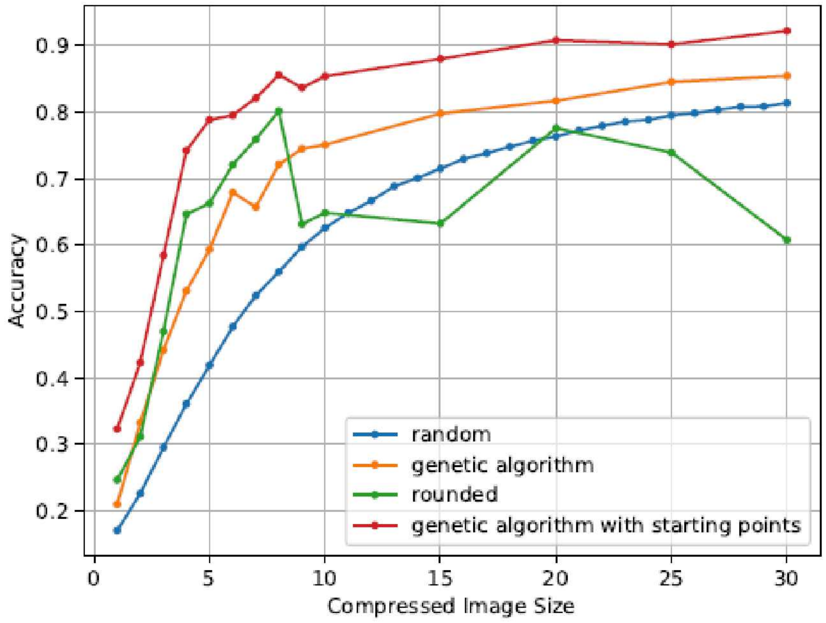
- Gradient-based methods
- Surrogate methods
  - Bayesian optimization using Gaussian processes
  - Mode pursuing sampling
- Heuristic methods
  - Grid search
  - Genetic algorithms

Genetic Algorithm Approach

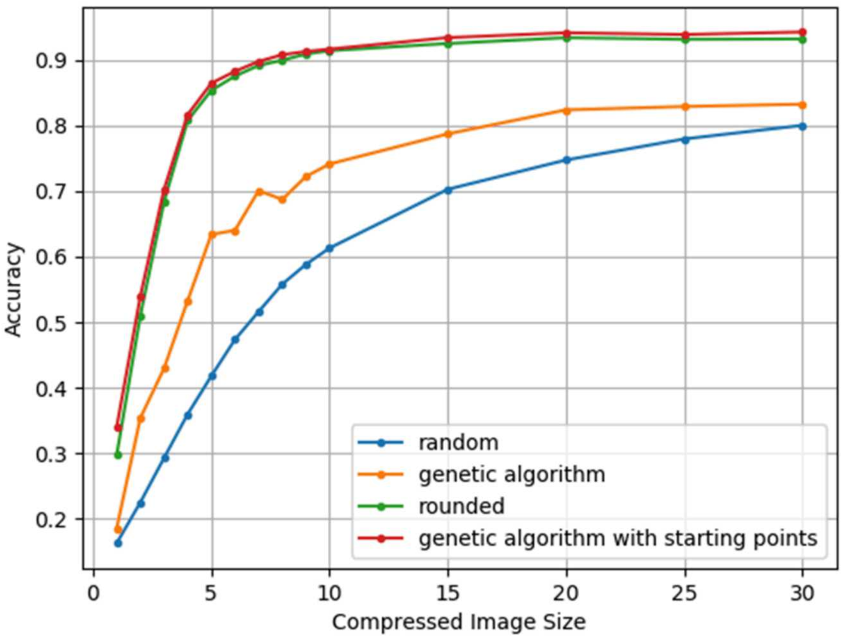


Ossai, Chinedu. (2018). Prognosis and Remaining Useful Life Estimation of Lithium-Ion Battery with Optimal Multi-Level Particle Filter and Genetic Algorithm. Batteries. 4. 15. 10.3390/batteries4020015.

Simulation Results: Genetic Algorithm Performance

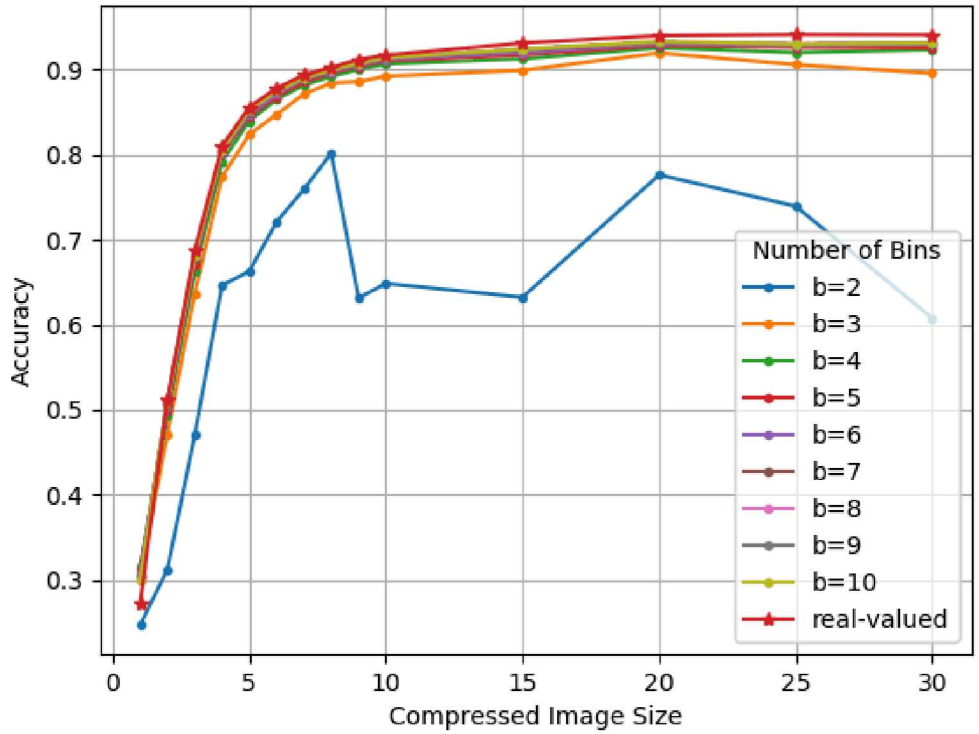


(a) Binary compression matrix
$B = \{0, 1\}$

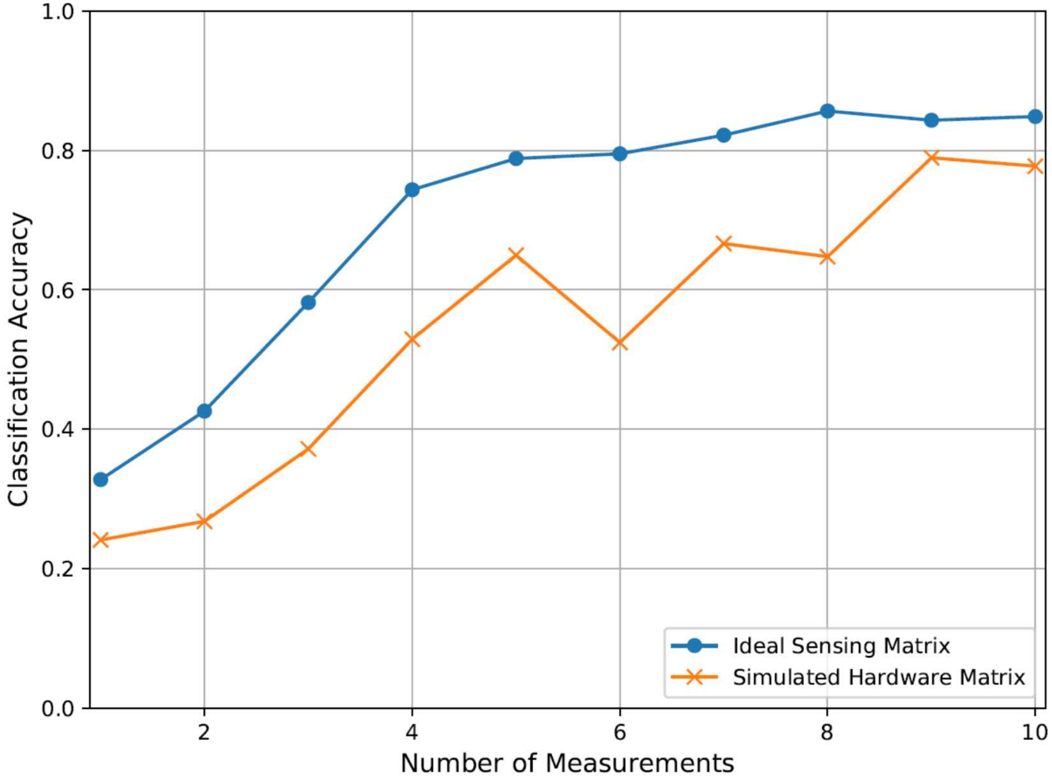


(b) One digit precision compression matrix
$B = \{0, .1, .2, .3, .4, .5, .6, .7, .8, .9, 1\}$

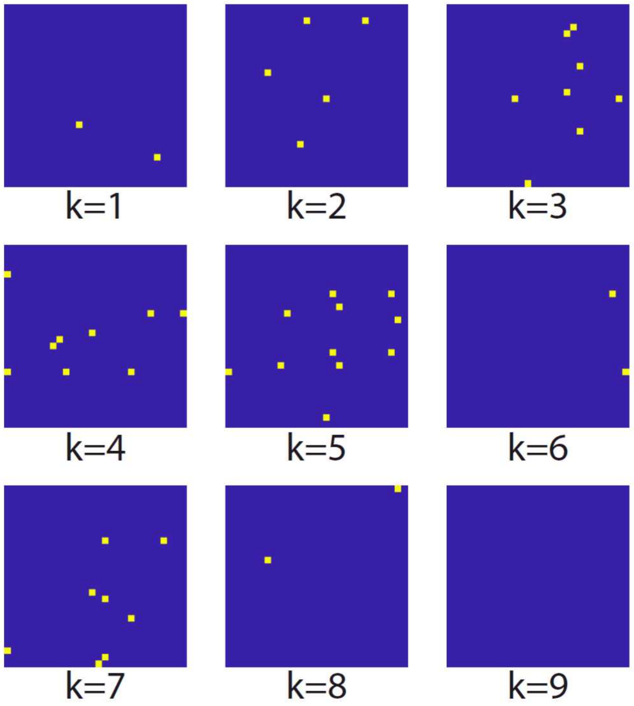
Simulation Results: Varying precision of compression matrix



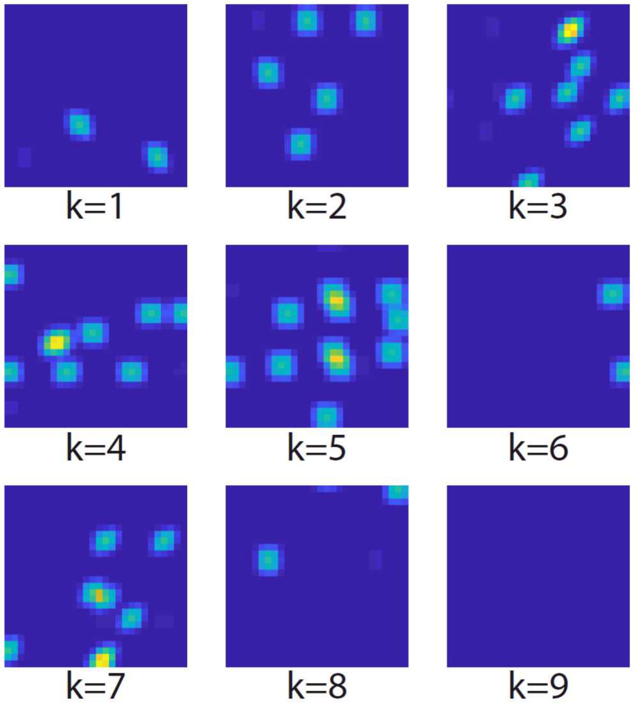
Simulation Results: Ideal versus simulated hardware



Simulation Results: Ideal versus simulated hardware



(a) Ideal binary compression matrix



(b) Simulated binary compression matrix

Future Work

- Algorithms
  - New binning schemes – ex. equally weighted bins
  - Additional investigation into optimization algorithms
  - Extensions to reconstruction and object detection
- Hardware
  - Device prototyping and manufacturing
  - Alternative device design – ex. diffractive arrays, waveguides