Object Detection for Hardware-Accelerated Task Planning

ENGINEERING HONORS PROGRAM
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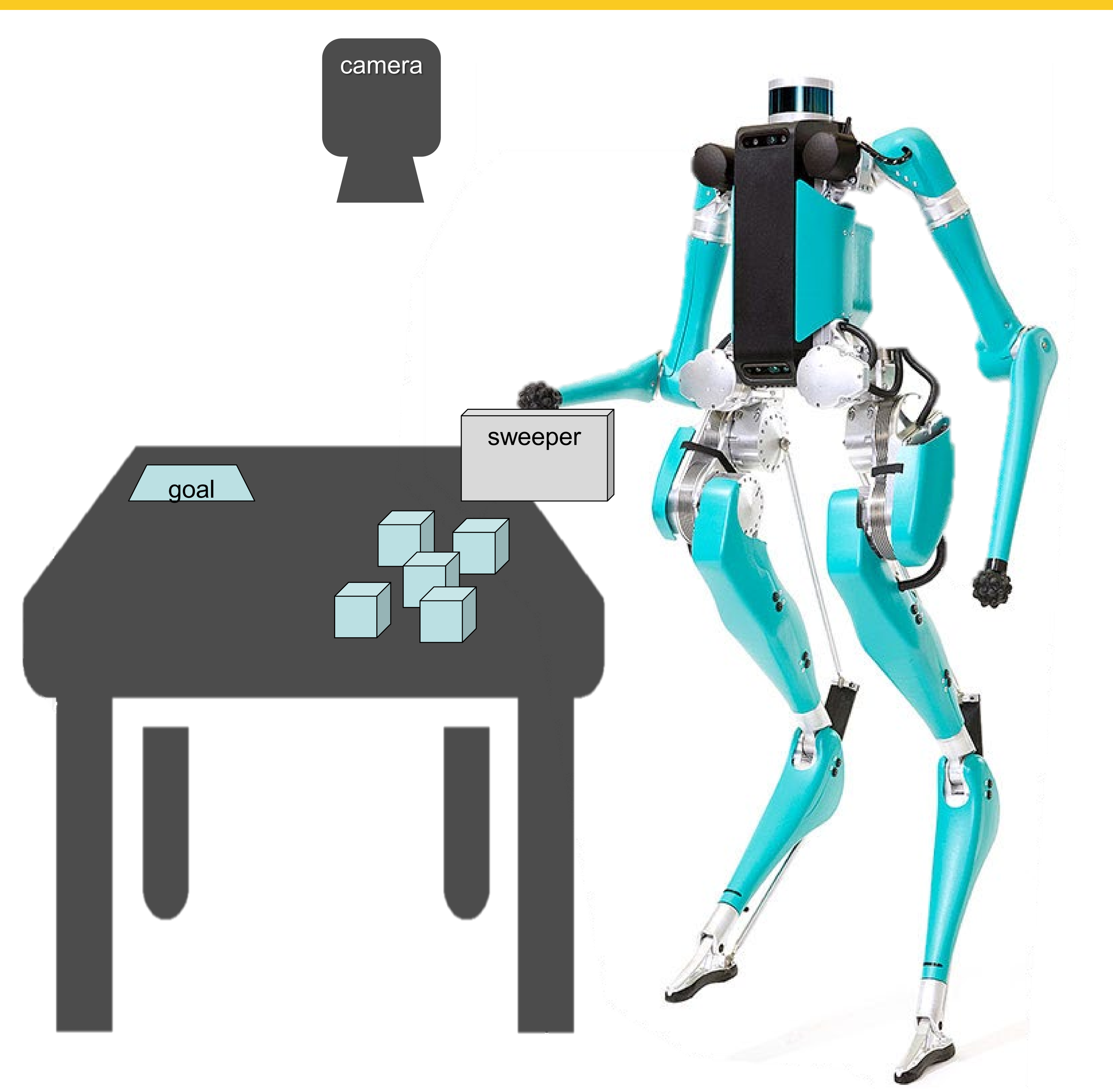
Introduction

Belief-space planning and probabilistic inference are two techniques used to inform the actions taken by autonomous robotic systems. These methods allow for fully autonomous systems to handle uncertainty about their observations, but require extensive computational resources and time, becoming prohibitive for robot systems that need to act in real time.

Our project is to design a perception-planning system for autonomous robots that requires less time and power by using parallel computing FPGAs to speed up belief-space planning algorithms.

My capstone work involved designing the perception system for a real-world experiment necessary to confirm the project's effectiveness. I implemented the components necessary to detect and localize colored blocks used in the experiment and interface with the parallelized planning code, which uses the blocks' locations to plan a robot's movements towards a goal configuration.

Experimental Setup

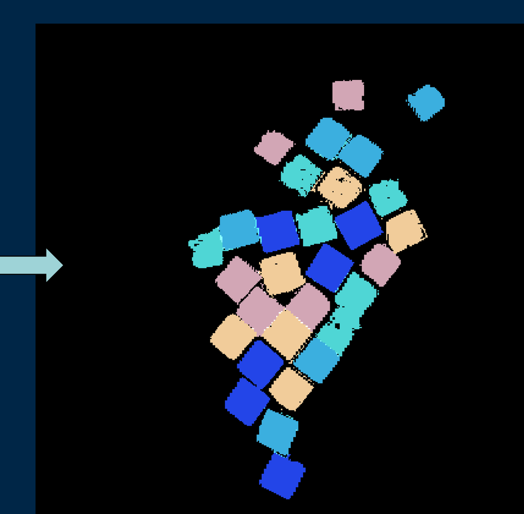


For our sweeping experiment, which requires a perception system, the Digit robot will manipulate[1] a sweeper tool to push colored blocks to a goal configuration, using an accelerated belief-space algorithm running on FPGA hardware.

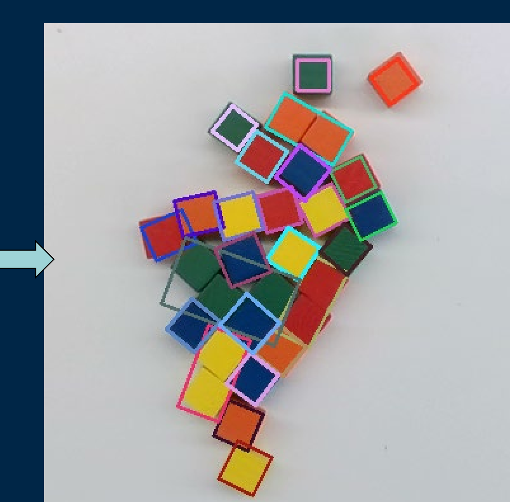
Object Detection Contribution

Detection Pipeline

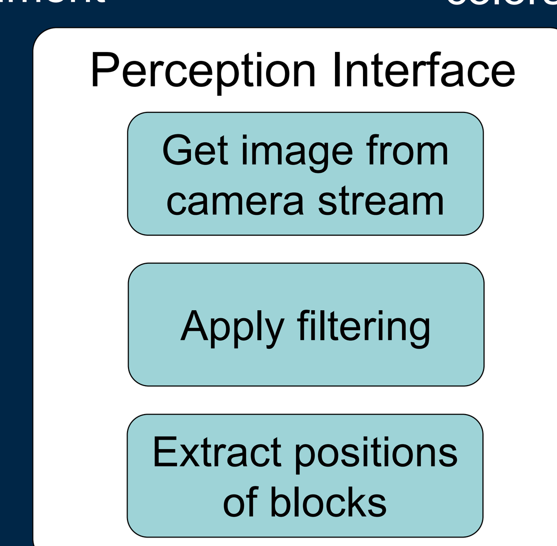
Input images from experiment



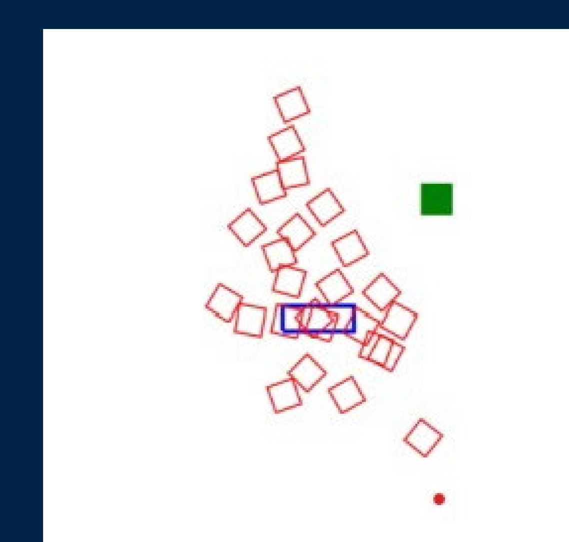
Apply thresholding for colors



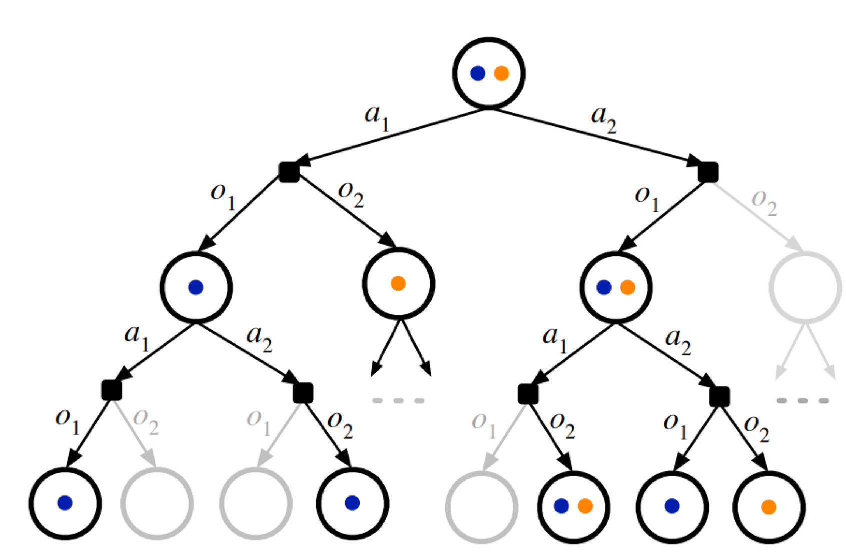
Find x, y, and theta of blocks



Python-Julia perception interface



Representation in exp. simulator



Our team's belief-space planning algorithm is based on DESPOT[2]. This method handles uncertainty about the state of the system by representing beliefs about the state of the world as scenarios (shown as colored dots). As an action a_1 is considered, the possible scenarios are updated based on possible observations o_1 and o_2. In our system, the configuration of the blocks are the scenarios.

Challenges

- Detect blocks without computer-vision-friendly borders to allow for a natural source of uncertainty
- Convert detections to real-world positions
- Develop interface between detection code implemented in Python to make use of OpenCV and belief-space planning system implemented in Julia

Results

- Determined experimental setup
  - Intel RealSense with depth channel for depth filtering
  - Thresholding and contouring by RGB or HSV values with OpenCV
- Developed interface for belief-space planning module
- Created test datasets of single-color, tri-color, and multi-color block configurations for benchmarking perception performance

Accuracy

Mode/Data	Multicolored	Primary	Red only
HSV	90.5%	79.2%	83.3%
RGB	91.8%	85.8%	49.8%

Accuracy of perception system on datasets of different block colors and different thresholding types.

The perception system is ready to be used in our team's experiments and works best with a RealSense RGB-D camera filtering on RGB values on the multicolored dataset. More testing and tuning can be done to verify the use of RGB over HSV.

Future Work

- Implement accelerated, parallelized belief-space planning algorithm on FPGA hardware
- Run block-sweeping experiment on Digit robot with perception system using baseline and updated implementations
- Tune HSV filters for more robust thresholding

Acknowledgements

[1] Adu-Bredu, A., Zeng, Z., Pusalkar, N., Jenkins, O.C. Elephants Don't Pack Groceries: Robot Task Planning for Low Entropy Belief . *IEEE Robotics and Automation Letters,* 7 (2022).

[2] Ye, N., Somani, A., Hsu, D., Lee, W. S. DESPOT: Online POMDP Planning with Regularization. *Journal of Artificial Intelligence Research,* 58 (2017), 231-266.

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