Key Capabilities of Autonomous Mobile Platforms for Maintenance and Monitoring in Manufacturing Environments

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Introduction

Motivation and Objectives

- Quadruped robots offer unique mobility for autonomous inspections in manufacturing environments.
- Tasks requiring fine manipulation still rely on human interference.
- We employed a Boston Dynamics' Spot robot[1] with an 6 DoF robotic arm for the case study of a feeder test.
- Evaluated a Spot and its arm's ability and reliability to identify, pick and place, and move a bucket with varying weights in manufacturing-like environments.

Contributions

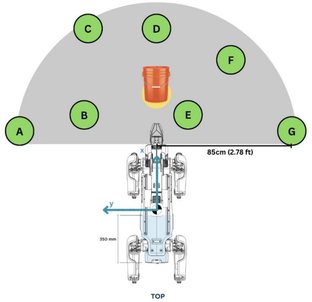
- We present systematic evaluations of Spot with an arm's ability to :
  - Pick up and move buckets with varying weights.
  - Maintain stability and precision during bucket manipulations.
  - Identify and approach the target object in a cluttered environment.
- Our experimental results provide insights into the capabilities and limitations of quadruped robots with manipulators for inspections and maintenance in manufacturing settings.

Robotic Arm Manipulation Evaluation

This section evaluates the Spot's arm performance through 3 phases:

1. Bucket Identification 2. Pick and Place Maneuvering 3. Weighted Bucket Manipulation

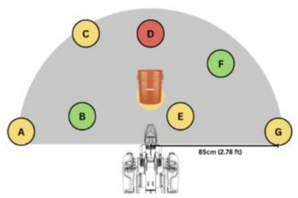
Experimental Setup:



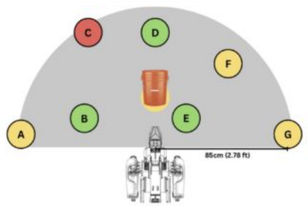
	X	Y
Starting Location in Spot's Body Frame (cm, cm)		
	84	0
Goal Locations in Spot's Body Frame (cm, cm)		
A	44	85
B	64	40
C	109	35
D	109	0
E	64	-20
F	94	-50
G	44	-85

Illustration and coordinates of the bucket and Spot's initial locations and goal locations during each trials.

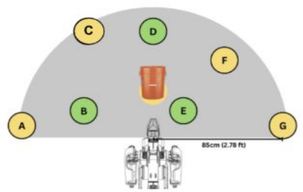
1 Bucket Manipulation with AprilTags is Sucessful



(a) Empty Bucket Workspace Test



(b) 5lbs Bucket Workspace Test



(c) Pick and Place Bucket on Back Test

	Avg Placement Dev.	Success Rate
(a)	3.8 (cm)	21/21
(b)	3.2 (cm)	21/21
(c)	3.5 (cm)	8/8

Average deviation is below the overall mean.
Average deviation is within 1 Std above the mean.
Average deviation is larger than 1 Std above the mean.

2 Pick and Place Maneuvering onto Spot's Back

t = 0s
Go to bucket

t = 2s
Lift bucket off ground

t = 8s
Bring bucket closer

t = 12s
Lift bucket above body

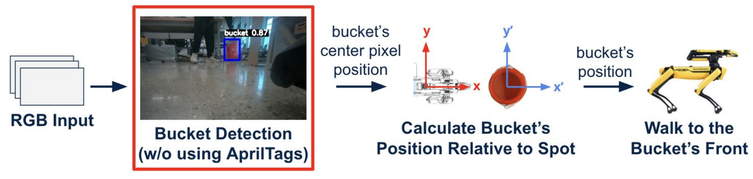
t = 15s
Rotate

t = 20s
Place on back

3 Weighted Bucket Manipulation is Limited

- **Methodology:** We tested the effect of weight the arm's pick-and-place tasks.
- **Results:** The arm successfully handled up to 17.5 lbs (7.94 kg) , but began dragging the bucket at 7.5 lbs (3.40 kg).

Bucket Detection in Manufacturing Environments



1 Pretrained Model with Color Verification Performs Unreliably

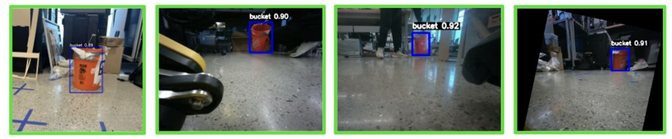
- **YOLO11n[3] model + Color Verification** (applied CLAHE, morphological operations, and HSV thresholding): failed to reliably detect the target bucket.

2 Reliable Detection Requires Spot Camera Training Data

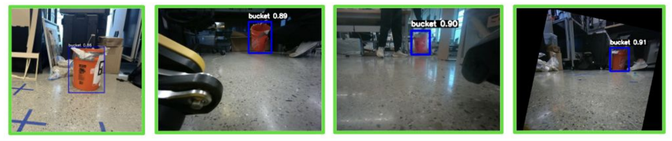
- **Custom bucket detection models trained with 3 datasets using YOLO11[3]**

(1) 85 images from a smartphone: failed to reliably detect with Spot's camera.

(2) 213 images from Spot's cameras: successfully detect the target bucket.



(3) 298 images from smartphone & Spot: successfully detect the target bucket.



Conclusions and Future Work

- Pick-and-place tasks achieved 100% success rates for each, with an average placement deviation of 3.8 cm (empty bucket) and 3.2 cm (5 lbs).
- Placing payloads up to 17.5 lbs on Spot's body improves stability and reduces collision risk.
- A custom-trained detection model reliably identifies the target object in manufacturing-like environments, but reliable detection requires datasets collected using Spot's onboard cameras in the target environment.
- **Future work:**
  - Autonomous target searching outside current field
  - Develop safe navigation in tight, dynamic areas
  - Assess Spot's capabilities of operating ball valves
  - Explore gesturing for object handover and navigation

Paper

References: [1] Boston Dynamics, "Spot - The Agile Mobile Robot," 2024. [Online]. Available: https://bostondynamics.com/products/spot/
[2] E. Olson, "Apriltag: A robust and flexible visual fiducial system," in *2011 IEEE International Conference on Robotics and Automation*, pp. 3400–3407, 2011.
[3] G. Jocher and J. Qiu, "Ultralytics YOLO11," 2024. [Online]. Available: https://github.com/ultralytics/ultralytics

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