Toward Reliable Sample Collection with Legged Robots

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Figure 1: Legged robot performing analogue tests in Marslabor at the University of Basel. Credit: Dr Tomaso Bontognali.

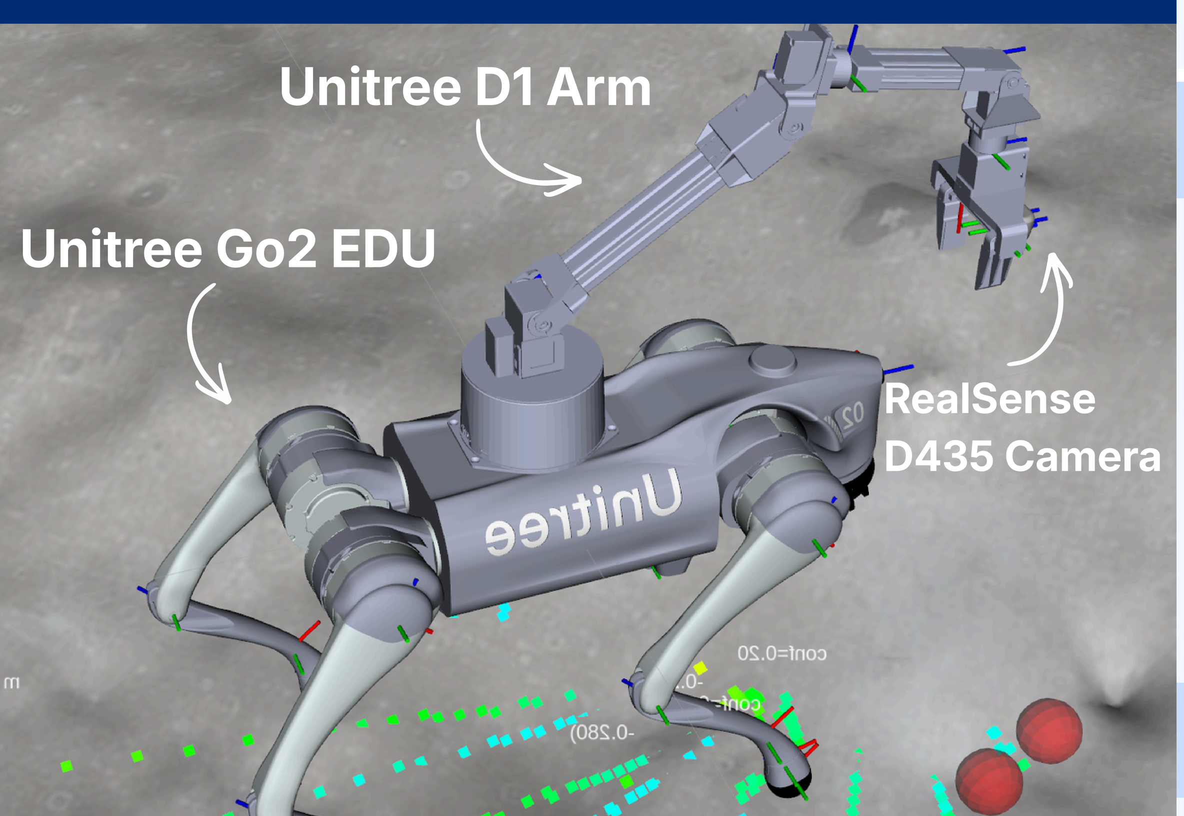
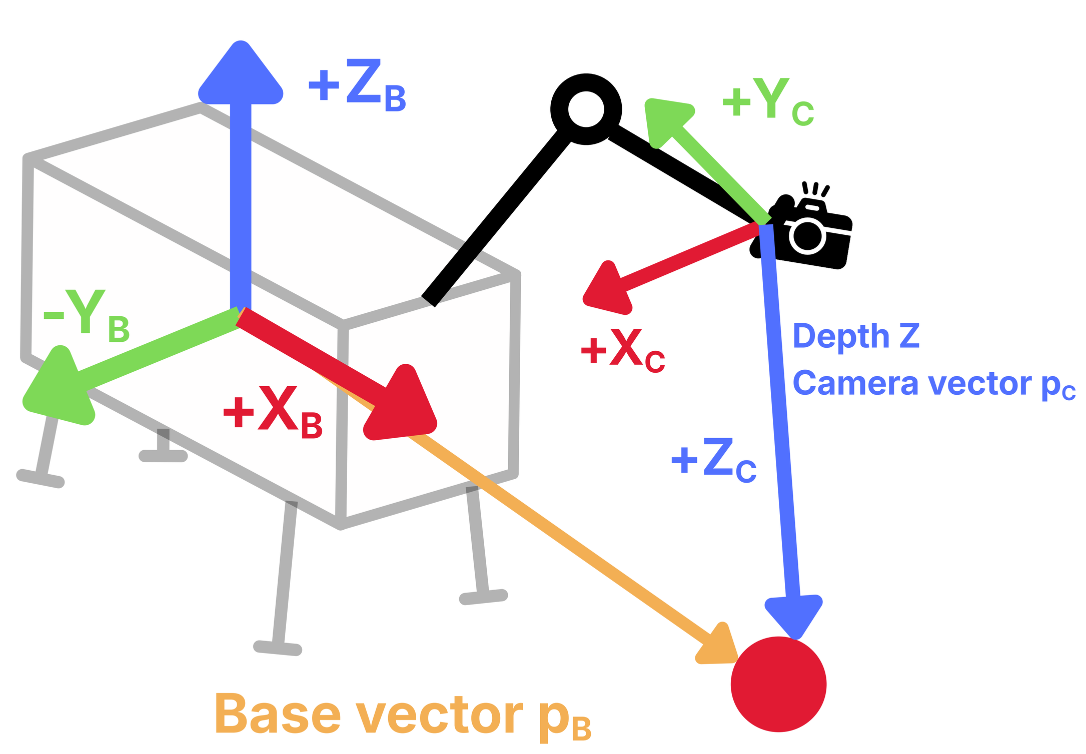


Figure 2: Simulation on MoonTrek terrain



Deprojection: Convert the target's image pixel (u,v) into a 3D camera frame position by taking the inverse of the camera's intrinsic matrix (K) and scaling by depth (Z).

$$\boldsymbol{p}_{\mathrm{C}} = \mathrm{Z}\,\mathrm{K}^{-1}\begin{bmatrix} \mathrm{u} \\ \mathrm{v} \\ 1 \end{bmatrix}$$

Rigid transformation: Convert the target's position from the camera frame (C) into the robot base frame (B) by rotating and translating it to account for the camera's location on the arm.

$$\begin{bmatrix} \boldsymbol{p}_{\mathrm{B}} \\ 1 \end{bmatrix} = \mathrm{T}_{\mathrm{B}\leftarrow\mathrm{C}}(\mathrm{q})\begin{bmatrix} \boldsymbol{p}_{\mathrm{C}} \\ 1 \end{bmatrix}$$

References

[1] Arm et al., Science Robotics 8(80) (2023), doi:10.1126/scirobotics.ade9548.
[2] Ligeza et al., Front. Space Technol. 7 (2026), doi:10.3389/frspt.2026.1741757.
[3] Nickels et al., Robot. Auton. Syst. 58 (2010), doi:10.1016/j.robot.2009.07.029.
[4] Boucher et al., "Integration of Vision-based Object Detection and Grasping for Articulated Manipulator in Lunar Conditions," arXiv:2309.01055 (2023).
[5] Parosi et al., "Kinematically-Decoupled Impedance Control for Fast Object Visual Servoing and Grasping on Quadruped Manipulators," arXiv:2307.04918 (2023).
[6] YOLO 26s Overview, https://docs.ultralytics.com/models/yolo26

Abstract

Planetary robots must do more than travel; they must also interact accurately with nearby samples and science targets. While wheeled rovers are proven for distances and precision, legged robots may help reach targets near large steps, loose slopes, or narrow spaces. This project develops a reliable collection system using a Unitree Go2 EDU, D1 arm, wrist-mounted RealSense D435, and YOLO26s. The robot detects and measures sample-like objects, turns when needed, stops, looks again after every movement, corrects the wrist view, and checks the target, arm solution, path, and feedback before grasping. It then lifts, verifies, sorts, or stops safely. A complete autonomous demonstration collected and sorted multiple samples without human interference.

Introduction

Traditional rovers remain effective for long travel, whereas legged robots such as quadrupeds may complement them at large steps, loose slopes, and narrow sites (Fig. 1)[1]. However, reaching the site is just the first step of a task as error accumulation can cause off-target arm placement and reduce success rate [2]. Prior work already shows planetary arm correction [3], lunar RGB-D grasping [4], and quadruped visual servoing [5]. We focus on a practical gap: reliable collection with a legged base whose unpredictable motion can shift the target before grasping.

Methodology

- **Detect:** YOLO26s[6] detects each object in the wrist-camera image and identifies its color (Fig. 3).
- **Calculate 3-D position:** The D435 depth (Fig. 4) is used to convert the image location into a camera-frame point, which is transformed into robot-base coordinates.
- **Position the robot:** if the object is too far to one side, the Go2 makes a small bounded turn, stops, and settles.
- **Look again:** every turn or posture change invalidates the old position, so the robot takes a new depth measurement before using the arm.
- **Align and plan:** the wrist camera centers the object, then inverse kinematics calculates joint angles for checked approach waypoints.
- **Collect and sort:** the arm descends, closes the gripper, lifts, checks the pickup, and sorts the object on the color-based side (Fig 5.).

Discussion

Compared with dynamic whole-body visual servoing [5], our method is deliberately simpler: stop the dog, measure again, check the arm path, then move. New measurements corrected for observed turn and posture error. A complete demonstration integrated object detection, posture change, fresh localization, wrist correction, pickup, verification, sorting, and automatic stopping. The goal is not to show that legs are better than wheeled robots, but rather how legged access can be paired with reliable local manipulation. Current tests remain limited to a flat floor and simple ball-shaped objects.

Learning Outcomes

- Operation and calibration: used the Unitree Go2 app for safe motion, then designed and 3-D printed a ruler to measure and calibrate leg and body movement.
- ROS 2 and communication: worked with nodes, topics, DDS networking, SDK commands, telemetry, TF, URDF, and RViz.
- Perception and robot math: applied YOLO, RGB-D sensing, coordinate transforms, forward kinematics, inverse kinematics, and path checks.
- System engineering: connected perception, arm control, safety checks, logging, testing, and recovery on physical hardware

Conclusion and Future Work

Legged planetary research has shown the value of difficult-terrain access [1,3]. This project addresses the next step: using an arm reliably after the robot arrives. Looking again, correcting the wrist view, checking the arm path, and stopping on bad evidence supported complete collection and sorting.

Future work:

- Integrate SLAM and Nav2 for room scale search and missions.
- Move YOLO inference to the onboard Orin Nano using TensorRT for perception locally.
- Calibrate LiDAR for map-based localization and obstacle avoidance.
- Test irregular objects, different lighting, and rougher terrain.

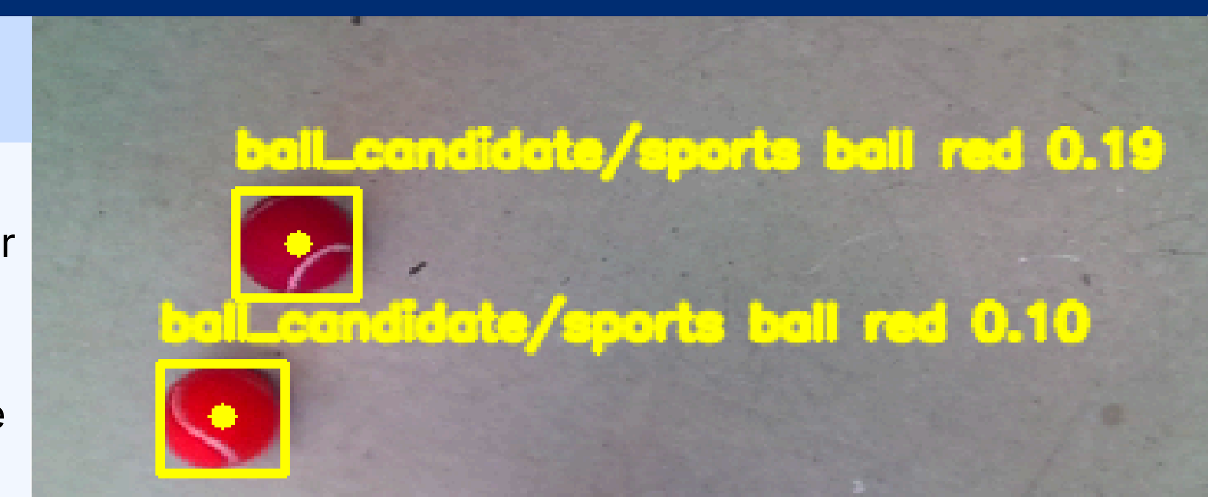
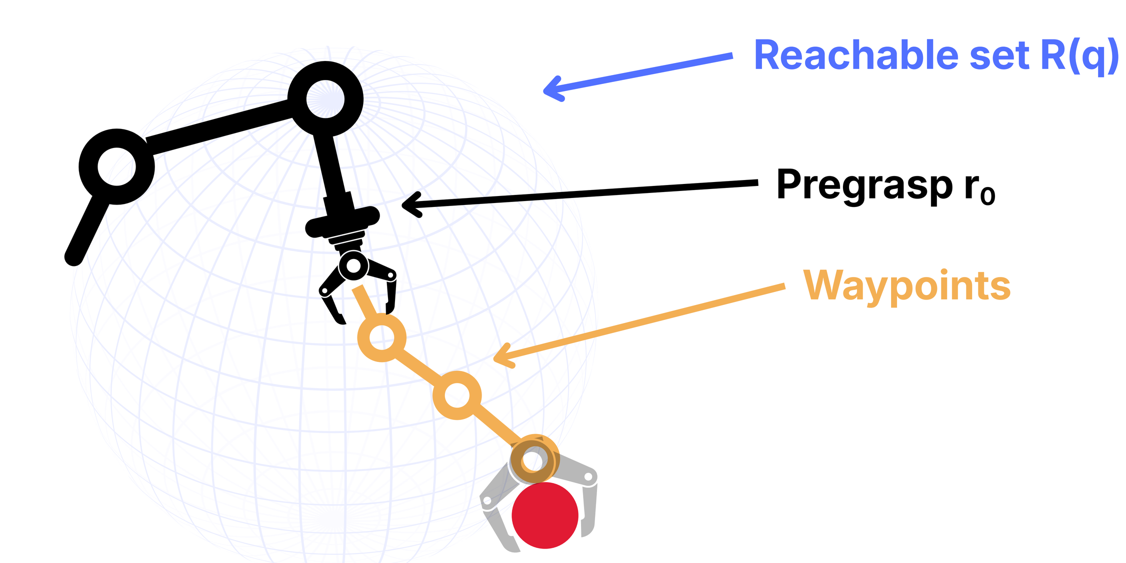


Figure 3: RGB Image from D435 with YOLO26s

Figure 4: Depth Image from D435



$$\boldsymbol{r}_{\mathrm{waypoint}} = (1-\mathrm{s})\boldsymbol{r}_{\mathrm{pregrasp}} + \mathrm{s}\boldsymbol{r}_{\mathrm{grasp}}$$

$$\mathrm{s} = \{0,\ 0.25,\ 0.50,\ 0.75,\ 1\}$$

Waypoint calculation: Each percentage places a waypoint between the pregrasp and final grasp position. The planner smoothly changes the gripper orientation between the two poses.

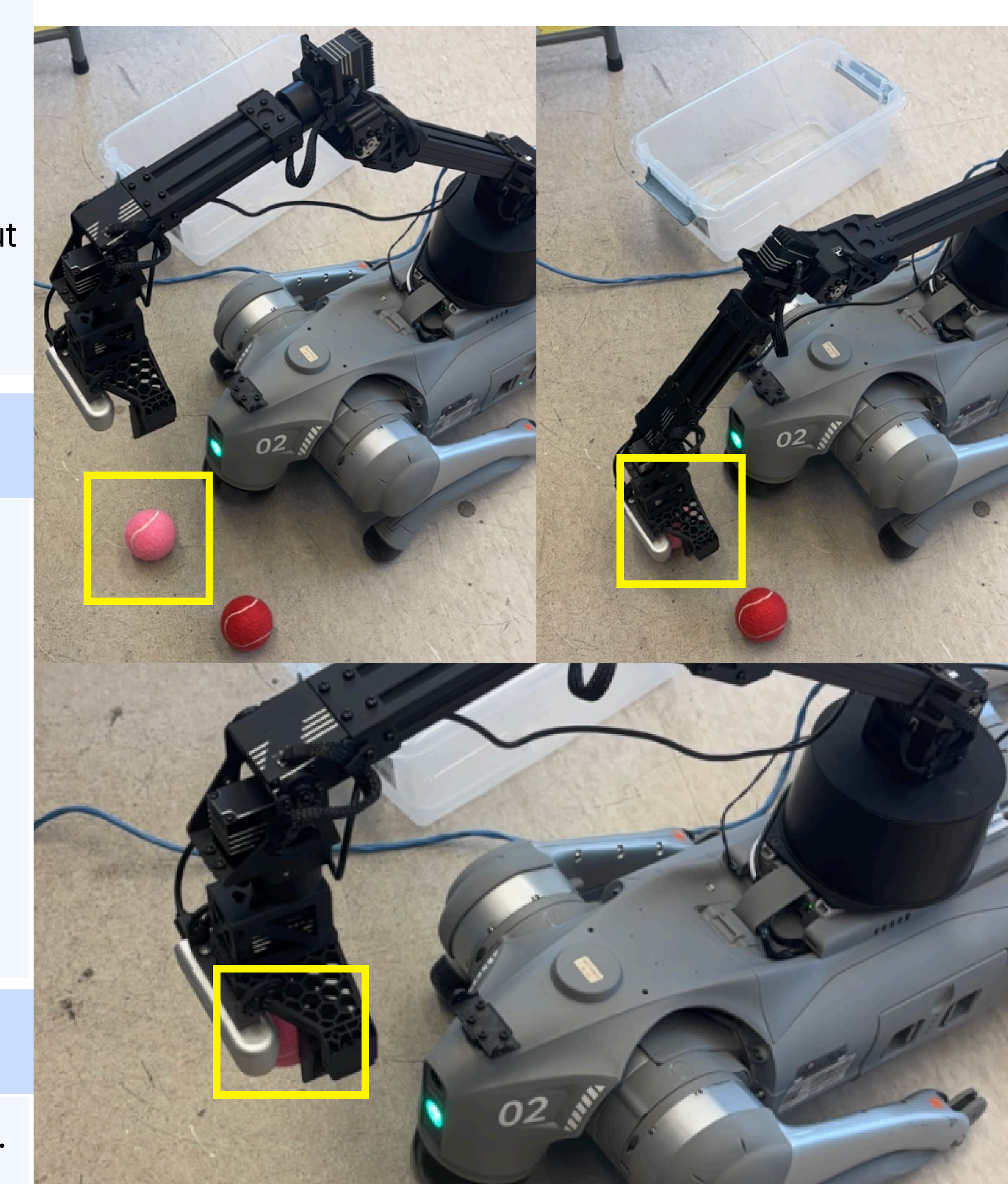


Figure 5: Pickup Cycle

Acknowledgements

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