

Low cost Extraterrestrial Surface Analysis Rover (LESAR): Repurposing Educational Robotics for Real World Planetary Research

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ABSTRACT

Space exploration is expensive, and one of the biggest challenges is figuring out where to land before sending a billion dollar mission. This paper presents LESAR (Low Cost Extraterrestrial Surface Analysis Rover), a student built planetary reconnaissance rover that was constructed for approximately \$300 by repurposing hardware from a Botball educational robotics competition kit. LESAR is equipped with sensors that measure soil moisture, gas concentrations, surface temperature, and soil nutrients, allowing it to scan a surface and identify areas worth exploring further. The rover was field tested on soil samples from three different locations in California and Utah, and successfully distinguished between dry and moist soil conditions, detected gas variations, and recorded temperature data. This paper explains what LESAR does, how it was built, and why repurposing Botball components made it possible to build a research grade rover as a student project.

I. WHAT IS LESAR AND WHY DOES IT MATTER?

Before any NASA mission lands on the Moon or Mars, engineers need to know where to go. Sending a rover to the wrong location wastes time and money. Ideally, a cheaper scout would scan the surface first and send back data to help mission planners choose the best landing site. That is exactly what LESAR is designed to do.

LESAR stands for Low Cost Extraterrestrial Surface Analysis Rover. It is a small, lightweight autonomous rover equipped with a scientific sensor suite that can measure several environmental conditions at once: how much moisture is in the soil, what gases are present near the surface, what the surface temperature is, and what nutrients like nitrogen, phosphorus, and potassium exist in the soil. These measurements help identify regions that might contain water, ice, or other scientifically valuable resources.

To put the cost in perspective, NASA's Perseverance rover cost approximately \$2.7 billion to build and launch. The VIPER lunar rover reached \$433.5 million before being cancelled in 2024. LESAR was built for approximately \$300. It cannot replace those missions, but it does not need to. Its job is to go first, scan cheaply, and help target where the expensive missions should go.

The key design decision that made this possible was building LESAR on a foundation that already existed: the Botball educational robotics platform.

II. FROM COMPETITION TO RESEARCH: HOW BOTBALL MADE LESAR POSSIBLE

Most Botball hardware gets used during competition season and then sits in storage. This project started from a different question: what if the same controller, motors, and sensors used to win a Botball competition could become the brain and body of a planetary rover?

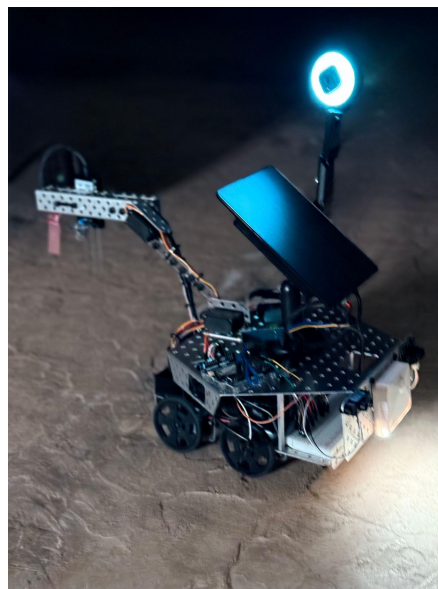
The answer is that they can. LESAR was built by extending an existing Botball platform with a scientific sensor payload, transforming a competition robot into a research instrument. The components had already been proven reliable through multiple competition cycles, including the 2024 Moonbase Mission where it won 1st Place Overall and 1st Place in Double Elimination. That operational history gave me confidence in the reliability of every component before a single science sensor was added.

This approach had three major advantages. First, the Botball components were already tested and proven. Second, it saved significant development time because the locomotion system did not need to be designed from zero. Third, it kept the total build cost to approximately \$300, which would not have been possible starting from scratch.

III. HOW BOTBALL COMPONENTS WERE REPURPOSED FOR LESAR

A. Component Overview

The table below shows each Botball component used in LESAR, what it originally did in competition, what it does in the rover, and why it was chosen for reuse:



Component	Original Botball Role	Role in LESAR	Why It Was Reused
KIPR Wombat Controller	Main controller	Drives motors and handles obstacle avoidance	Already supports 4 DC motors and 2 servos; runs proven navigation code
DC Drive Motors (x4) & Mecanum Wheels (x4)	Move and swerve the robot	Propel the rover across soil surfaces	Strong enough torque to carry the full sensor payload and better traction for rugged surfaces
Servo Motors (x3)	Actuate arms and mechanisms	Move the camera arm and soil sampling arm	Precise position control needed for repeatable soil contact
IR Rangefinder (GP2Y0A)	Detect walls and objects	Detect obstacles in the rover path	Already tested and calibrated; 80 cm range is sufficient for prototype
Chassis Frame Parts	Structural base of robot	Foundation for the rover body	Provided mounting geometry; upgraded with stainless steel panels
LEGO Camera Arm Parts	Building kit components	Lightweight arm to hold the camera	Low weight keeps the rover balanced during soil probing

B. The KIPR Wombat Controller: Navigation Brain

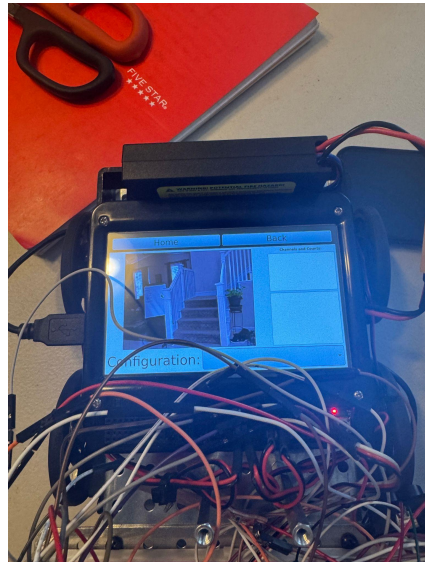
In Botball, the Wombat controller runs the autonomous competition routine: drive forward, detect a wall, turn, pick up an object, score a point. In LESAR, it runs a very similar type of program, called reactive navigation. Here is how it works:

1. The Wombat continuously reads the IR rangefinder sensor plugged into analog port 5.
2. If the sensor reading goes above 1,200 ADC counts, that means an obstacle is close.
3. The Wombat then executes an avoidance routine: stop, turn 90 degrees using the left and right motors at opposite speeds for 1,400 milliseconds, drive forward for 2,000 milliseconds, correct the turn, and resume normal driving.
4. When no obstacle is detected, all four motors run forward at full speed.

The navigation code in LESAR is directly adapted from Botball competition code. The same logic used to navigate an arena was repurposed to navigate a soil test surface. No new motor control system needed to be designed.

One important adaptation was running the Wombat alongside a second controller, an Arduino UNO R4, at the same time. The Wombat handles all movement. The Arduino handles all

scientific data collection. They run simultaneously without interfering with each other, which keeps the system modular and easier to upgrade later.



C. DC Motors: Driving Across Soil & Mecanum Wheels

The four DC motors from the Botball kit provide what is called differential drive, meaning the left and right sides of the rover can be controlled independently to steer. Each motor is rated at 9.75 lbs-in of torque and moves at 0.11 seconds per 60 degrees of rotation. In Botball competition, these motors had to move a robot quickly across a smooth arena floor. In LESAR, they move the rover across uneven soil test surfaces while carrying the full weight of all the sensors and the chassis.

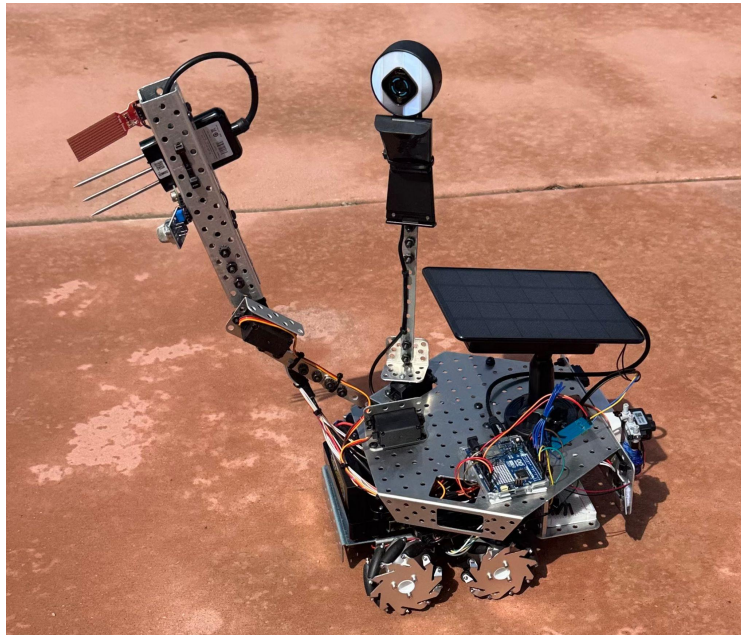
The Botball kit wheels were upgraded to Mecanum wheels; also available for purchase on KIPR's website, which have rollers mounted at 45 degree angles around the rim that allow the rover to move in any direction, including sideways, without needing to turn first. This omni-directional movement is especially valuable on uneven soil surfaces where a traditional wheeled robot might struggle to reposition its sensors accurately.

D. Servo Motors: Positioning the Arms

Three servo motors from the Botball kit control two different arms on LESAR. One servo controls the camera arm, which adjusts the camera angle to capture terrain images. The other two control the robotic soil sampling arm, which lowers sensors into direct contact with the soil surface.

Servo motors are ideal for this job because they rotate to a specific angle and hold that position precisely. In Botball, servos are used to grab objects or flip mechanisms. In LESAR, that same precise positioning is what ensures the soil moisture sensor and NPK sensor make consistent,

repeatable contact with each soil sample. The servo control library from the Wombat was used without any changes.



E. Infrared Rangefinder: Analyzing Ahead

The GP2Y0A infrared rangefinder sensor detects how far away an object is by bouncing infrared light off a surface and measuring how long it takes to return. It has a maximum detection range of 80 cm and operates at a wavelength of 940 to 800 nm. In Botball, this sensor is used to detect arena walls and nearby objects during competition.

In LESAR, it serves as the primary obstacle avoidance sensor. When the rover is moving across a surface, the rangefinder continuously checks if anything is in the way. If an object is detected within range, the navigation routine described above kicks in automatically. Because this sensor had already been tested and calibrated during Botball use, its behavior was already well understood.

F. Structural Frame and LEGO Camera Arm

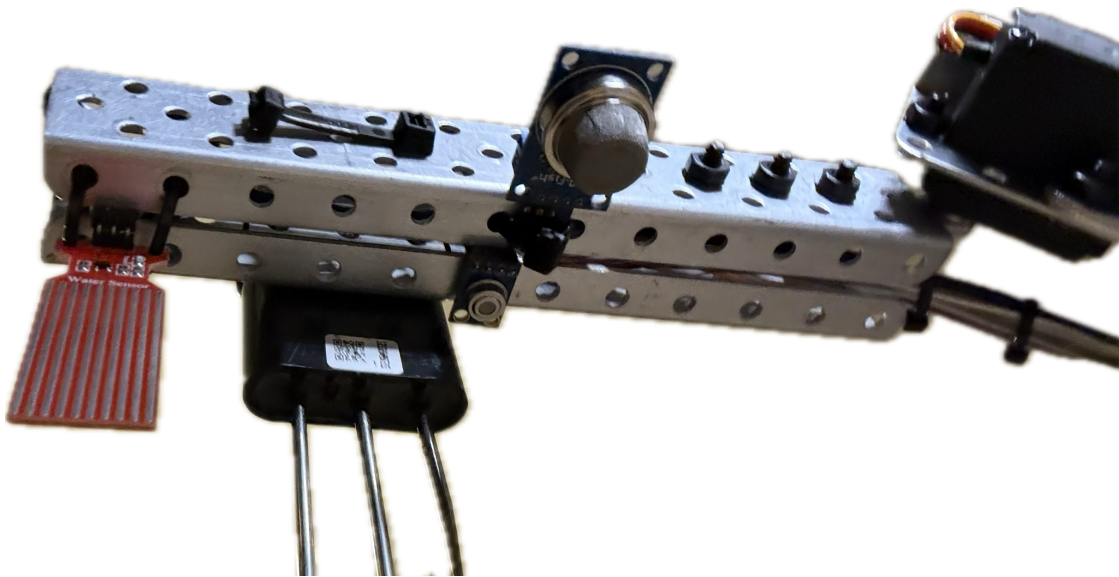
The base chassis frame geometry came from the Botball structural platform, which was then upgraded by adding perforated stainless steel panels for durability and corrosion resistance. The total rover measures 10 inches by 10 inches with the robotic arm extending an additional 13 inches, and weighs approximately 6 pounds fully assembled.

The camera arm is built from LEGO-compatible components that came with the Botball kit. LEGO parts were chosen deliberately because they are very lightweight. On a small rover, keeping weight low and centered is important: if the camera arm were heavy, the rover could tip forward during soil probing. The lightweight LEGO arm keeps the center of gravity stable, while the heavier stainless steel sampling arm is positioned low and toward the front to balance the design.

IV. THE SCIENTIFIC SENSOR PAYLOAD

Everything described above handles locomotion and navigation. What makes LESAR a scientific instrument rather than just a moving robot is the additional sensor layer controlled by the Arduino UNO R4 WiFi board. These sensors were purchased specifically for this project and were not part of the Botball kit:

1. LIDAR Sensor: maps the terrain ahead by sending laser pulses and measuring how long they take to return. Operates via a high-speed serial connection at 115,200 baud.
2. Infrared Temperature Sensor (MLX90614): measures the surface temperature of soil or objects without making contact. Readings are averaged over 10 samples to reduce noise.
3. Soil Moisture Sensor: a resistive sensor that measures how much water is in the soil. Outputs a number from 0 (completely dry) to approximately 1023 (saturated). Values of 500 or above are classified as moist.
4. Gas Sensor Suite (MQ-135 and MQ-8): detects carbon dioxide, oxygen, and hydrogen concentrations near the surface. Sensors warm up for 60 seconds before readings are taken to establish an accurate baseline.
5. NPK Sensor: measures soil nutrients, specifically nitrogen, phosphorus, and potassium, in milligrams per kilogram. Connects via a Modbus RTU serial protocol.
6. USB Camera: connected to the Wombat, captures images of the terrain for documentation.



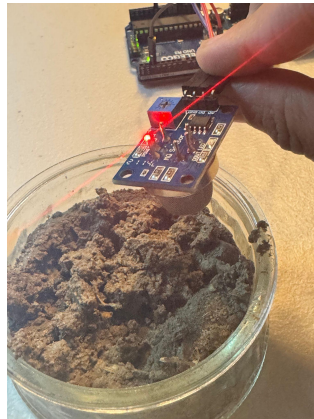
All sensor data collected by the Arduino is transmitted wirelessly through its built-in WiFi chip to a base station. A microSD card also logs a backup of every reading in CSV format in case the wireless connection is lost. This two-controller system, one for movement and one for science, means that either side can be upgraded without rebuilding the other.

V. FIELD TESTING AND RESULTS

LESAR was tested on soil samples collected from three different geographic locations to see if the sensors could detect real differences between them:

1. Mariposa County, California: Sierra Nevada foothill region, rich organic soil
2. Washington County, Utah: high desert terrain, dry and mineral-dense
3. San Diego County, California: coastal chaparral, sandy composition

Each sample was tested under four water conditions: dry with no water added, and then with 15 mL, 20 mL, and 40 mL of distilled water added per 100 grams of soil.



A. Soil Moisture Results

The moisture sensor worked reliably across all three samples. In dry conditions, readings ranged from 7 to 78 ADC counts, well below the 500-count moist threshold. After adding just 15 mL of water, all samples immediately read as moist, with values between 588 and 712 ADC counts. The San Diego sample consistently read slightly lower at full saturation (667 counts compared to 752 for Mariposa), which is consistent with its sandier texture holding less water.

B. Gas Sensor Results

Baseline gas readings matched standard atmospheric levels: oxygen between 17.4% and 20.9%, carbon dioxide between 331 and 421 parts per million, and hydrogen between 4.52% and 4.73%. A slight increase in CO₂ was observed as water was added to the samples, most noticeably in the Mariposa sample where CO₂ rose from 333 ppm in dry conditions to 420 ppm at 20 mL of water. This could reflect increased microbial activity in moist soil and is worth investigating further in a controlled lab environment.

C. Temperature Results

Surface temperature readings stayed between 21.10 degrees Celsius and 22.31 degrees Celsius across all samples, which was expected since tests were conducted indoors in a controlled environment. The infrared temperature sensor functioned correctly throughout. In a real

outdoor or space simulated deployment, temperature differences between samples would be far larger and potentially indicate subsurface ice or shadowed regions.

Experiment Results

The logo for LESAR, featuring a stylized blue and red circular graphic with a grid of dots, and the word "LESAR" in a bold, sans-serif font below it.

MOISTURE LEVELS

SAMPLE	WATER (0 ml)	WATER (15 ml)	WATER (40 ml)
MARIPOSA Co., CA	78	712	752
WASHINGTON Co., UT	17	710	743
SAN DIEGO Co., CA	7	588	667

GAS LEVELS

SAMPLE	O ₂ (%)	CO ₂ (ppm)	H (%)
MARIPOSA Co., CA	17.4	333	4.56
WASHINGTON Co., UT	20.6	350	4.64
SAN DIEGO Co., CA	21	400	4.6%

SOIL FERTILITY (NPK)

SAMPLE	N (mg/kg)	P (mg/kg)	K (mg/kg)
LUNAR REGOLITH	< 5	5 - 30	50 - 100
MARS REGOLITH	0 - 20	10 - 50	80 - 150
SENSOR READING (SAN DIEGO)	31	63	231



VI. WHAT THIS MEANS FOR EDUCATIONAL ROBOTICS

The most important takeaway from LESAR is not the rover itself. It is what the rover proves about Botball hardware.

Every skill built in a Botball competition, writing motor control code, integrating sensors, designing for autonomous behavior, debugging hardware in real time, is a skill that transfers directly to building a research instrument. The gap between a competition robot and a research rover is smaller than most students realize. The same controller that navigated an arena can navigate a soil surface. The same servo that grabbed a game piece can position a scientific sensor.

The \$300 total cost of LESAR was only possible because of the Botball component reuse. Purchasing a comparable motor controller, four DC motors, two servo motors, and an IR sensor separately would have added hundreds of dollars and significantly more time to the project. Students who already have a Botball kit from a prior season are, in effect, already partway to building their own research rover.

VII. CONCLUSION

LESAR demonstrates that a student with access to a Botball robotics kit and approximately \$300 in additional sensors can build a functional planetary surface reconnaissance rover. By repurposing the KIPR Wombat controller, DC and servo motors, IR rangefinder, and structural components from the Botball competition platform, and by adding a scientific sensor payload on an Arduino UNO R4, this project achieved a working prototype that successfully characterized soil conditions across three geographically distinct samples.

The main conclusions from this work are:

1. Botball hardware is directly compatible with rover class research applications, requiring no fundamental modification to the controllers, motors, or sensors.
2. A two-controller architecture, with the Wombat handling locomotion and the Arduino handling science, cleanly divides the system and makes it easier to improve one part without rebuilding the other.
3. The sensor suite successfully detected real differences in soil moisture, gas concentrations, and surface temperature across different soil types.
4. This development approach is reproducible by any Botball team willing to invest in a small supplementary sensor kit.

Educational robotics competitions should be seen as the beginning of a research journey, and LESAR is proof that those two paths can be the same path.

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