CASE STUDY REPORT

BEAM ROBOTICS

XCSHA -3

INTRODUCTION TO MEACHINE LEARNING

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1. Introduction

BEAM robotics, an acronym for Biology, Electronics, Aesthetics, and Mechanics,is a branch of robotics that focuses on creating simple, efficient, and life-like machines using analog circuits rather than microprocessors. Unlike conventionalrobots that rely on complex programming, BEAM robots are built from minimalelectronic components such as capacitors, resistors, transistors, and solar cells. Their behavior emerges from the interaction of these circuits with the environment, mimicking biological responses like moving toward light, avoiding obstacles, or reacting to sound.

This approach was pioneered in the late 1980s by Canadian roboticist Mark W. Tilden, who emphasized the principle of "form follows function"-robots should bedesigned for purpose and simplicity rather than complexity. BEAM robots areoften powered by renewable sources like solar energy, making them highlysustainable and eco-friendly.

Because of their low cost, robustness, and minimal design, BEAM robots are widely used in education, research, and hobbyist projects. They encourage creativity, hands-on experimentation, and recycling of old electronic parts, offering an accessible entry point into robotics and electronics.

BEAM (Biology, Electronics, Aesthetics, and Mechanics) robotics is a minimalist, analog-first approach to building autonomous mobile robots. Rather than relying on microcontrollers and software, BEAM robots use simple analog circuits, natural feedback, and clever mechanics to produce lifelike behaviors such as seeking light, avoiding obstacles, and following lines. This case study documents the design, build, and evaluation of two BEAM-style robots: (i) a line follower and (ii) an obstacle detector/avoider.

2. Problem Statement

Design two resource-constrained mobile robots that demonstrate robust autonomous behavior using primarily analog circuitry and passive mechanics:

Line Follower: Track and navigate a high-contrast path (black line on white surface) with minimal components.

Obstacle Detector/Avoider: Detect and avoid obstacles in unstructured indoor settings without digital computation.

Constraints: low cost (< 1,500 per bot), low power (solar or 2xAA), small footprint (< 12×12 cm), and reproducible with entry-level tools.

Success criteria:
(a) stable behavior on varied surfaces/lighting,
(b) repeatable performance over 10 trials,
(c) quick recovery from disturbances, and
(d) simple-to-tune circuits.

3. History of BEAM Robotics

1980s: Concept pioneered by Mark W. Tilden, a Canadian roboticist.

1990s: BEAM robotics gained popularity in educational and DIY communities.

Core Principle: "Form follows function" robots should be simple, efficient, and directly linked to their purpose.

Expansion: Development of "Nervous Networks" (Nv networks), solar engines, and various robot types such as walkers, poppers, and photovores.

4. Literature Review (Selected)

BEAM community documentation (Solarbotics, community zines) describing Nv neurons, bicore oscillators, and solar engines.

Hrynkiw & Tilden (2002) JunkBots, BugBots, and Bots on Wheels-practical BEAM circuits and behaviors.

Hobby/academic articles comparing analog reflex loops to microcontroller-based control for simple navigation tasks

5. Approach

Design principles

1. Use Schmitt-trigger inverters (74HC14) for robust thresholding of noisy sensor signals.

2. Implement diff-drive steering via differential motor drive: stronger signal on one side reduces that wheel's PWM-equivalent (via analog modulation) and turns the robot toward the target.

3. Favor passive filtering (RC) and hysteresis over software debouncing.

4. Provide mechanical compliance: caster wheel, soft tire compound , and chassis layout that tolerates minor collisions.

5. Choose power strategy: (A) solar engine + storage capacitor for demos under strong light, or (B) 2xAA NIMH for consistent trials.

Common hardware set

Chassis: acrylic/3D-printed base plate (120×100 mm) with caster.

Drive: 2x DC gear motors (N20, ~200-300 RPM @ 6 V) with rubber wheels (43-65 mm).

Sensors: IR reflectance pair (line follower); IR photodiodes or bump switches (obstacle bot).

Electronics: 74HC14, 74HC240 (optional buffers), small-signal NPNs (2N3904) or MOSFETS (A03407/IRLML6344), diodes (1N4148), RC networks, trimpots (10-50 KΩ), motor diodes.

Power: 2×AA or 5-6 V solar panel + 4700-10,000 µF storage cap + Miller solar engine (1381/3906 variant).

6. Case Description

6.1 Line Follower (Analog Reflex)

Behavior goal: Follow a black electrical tape line (18-20 mm wide) on a light background at 0.2-0.5 m/s.

Sensing: Two IR reflectance sensors (left/right). Black absorbs IR → lower reflectance → lower phototransistor current.

Signal conditioning: Each sensor → RC low-pass (e.g., 10 kΩ, 0.1 µF) → 74HC14 Schmitt trigger.

Control (cross-coupled):

Left sensor drives right motor; right sensor drives left motor (negative feedback toward the line).

Motor drive via NPN/MOSFETs; optional series resistor for analog "PWM-like" control.

Trimpots set detection thresholds and balance.

Mechanics: Sensor module mounted ~5-7 mm above floor, 12-20 mm ahead of axle to increase phase lead.

Tuning steps

1. Set thresholds so white = logic 1, black = logic 0 at the Schmitt output.

2. Balance gains so the robot oscillates slightly about the line, then add RC damping to reduce overshoot.

3. Validate on straights, gentle turns (R > 20 cm), and junctions (teed merges ignored for this scope)

6.2 Obstacle Detector/Avoider (Reflex + Inhibition)

Behavior goal: Navigate a 1.5×1.5 m arena with random box obstacles (10-20 cm) and avoid collisions.

Sensing options (selected):

IR proximity: 38 kHz modulated IR LED + photodiode pair per side; range ~10-25 cm.

Whisker/bump: spring steel whiskers closing a switch on contact (backup reflex).

Signal conditioning & control:

Each proximity channel → bandpass (38 kHz) → 74HC14.

Winner-take-all Nv pair (bicore): detection on left inhibits left motor & boosts right motor for a corrective turn; symmetric for right.

Escape reflex: sustained contact via whisker triggers a timed reverse-turn (RC monostable ≈ 300-600 ms) before resuming forward.

Energy strategy: AA supply for consistent tests; optional solar engine demo under 1,000+ lux lighting.

7. Analysis

Metrics & tests

Line follower:

Tracking accuracy (mean lateral error, cm), lap time on 10 m course, max curve rate (min turning radius).

Robustness under variable ambient light (±30%).

Obstacle avoider:

Collision rate (#/minute), recovery time post-contact (s), coverage (area explored in 3 minutes).

Observed performance (representative targets)

Line follower: ≤ 1.5 cm mean lateral error; completes 10 m in 25-35 s; handles R ≥ 18 cm turns; no derail under overhead lighting change.

Obstacle avoider: ≤ 0.2 collisions/min with IR working; recovery ≤ 0.7 s on whisker hits; explores ≥ 70% of arena in 3 minutes.

Add a subheading

Analog simplicity → fast reflexes, low cost, but limited "task-level" intelligence.

Sensor placement and hysteresis are as critical as circuit topology.

Solar power is compelling but demands bright, stable light; batteries improve repeatability.

8. Solution (Final Designs)

Line Follower Schematic (block): Sensors → RC filters → 74HC14 (2ch) → cross-coupled motor drivers (NPN/MOSFET) → motors.

Key component values:

RC filter: 10 kΩ/0.1 μF; Hysteresis inherent to 74HC14.

Threshold trim: 20 ko trimpots per channel.

Flyback: 1N4148/1N5819 across motors; supply decoupling 100 nF + 470 μF bulk.

Obstacle Avoider Schematic (block): IR Tx (38 kHz) & Rx → bandpass/detector → 74HC14 → Nv bicore (mutual inhibition) + monostable → motor drivers → motors; whiskers into monostable.

Key component values:

IR modulation: 555 @ ~38 kHz, 20-30% duty.

Bicore timing: R = 47-100 KΩ, C = 1-4.7 μF (tune turning bias).

Escape monostable: R = 330 KΩ, C = 1 μF →~0.33 s (adjust as needed).

Build notes:

Keep sensor wiring short; star-ground the logic; isolate motor noise with RC snubbers if needed (1000 + 0.1 μF).

Aim sensor FOV ~15-25°; shroud to reduce ambient IR.

Mechanically align wheels; use compliant tires; ensure center of mass is low and centered.

9. Outcomes

Both robots meet cost and size constraints.

Line follower demonstrates smooth, continuous tracking with quick disturbance recovery.

Obstacle avoider shows reliable avoidance and graceful recovery from contact, with low collision rate.

Analog-only approach validated: no firmware required, immediate startup, easy classroom reproducibility.

10. Conclusion

BEAM-style analog control remains a powerful approach for simple autonomous behaviors where low cost, fast reflexes, and robustness matter more than feature richness. With careful sensor placement, hysteresis, and mechanical tuning, both a line follower and an obstacle avoider can achieve dependable real-world performance using only a handful of components.

11. References

1. Dave Hrynkiw & Mark Tilden, JunkBots, BugBots, and Bots on Wheels, McGraw-Hill/Osborne, 2002.

2. Solarbotics BEAM resources and community archives (Nv neurons, bicore, solar engines).