Complex Behavior from a Simple Rule: Demonstration with Lego Mindstorms NXT Kit

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Objective

- To demonstrate that sophisticated animal behavior can result from very simple rules encoded in neurons.

Background

- Perception and action are linked by decision making. How?
- Mechanical systems have been used by Professor Barbara Webb in perception and behavior studies, and specifically for her work on female mating cricket.
- Bat's navigation behavior is consistent with the use of Echoic Flow. Echoic Flow is the time to collision between two objects.
- The Lego Mindstorms NXT robot kit has been used to investigate the female mating cricket and Echoic Flow.

Demonstrations

- Mimic the female cricket's behavior of locating her mate with only sound signals using two sound sensors and two motors.
- Be able to freely navigate in an open space with obstacles using the echoic flow in a manner similar to a bat.

Fig.1: The Sound Source Seeking Robot

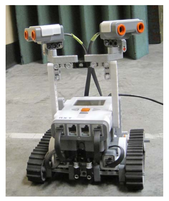
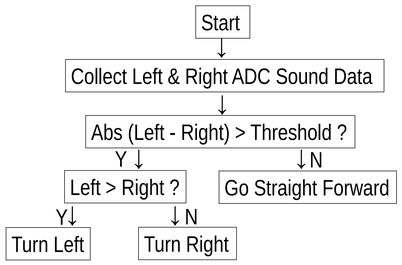


Fig.2: The Autonomous Navigator

Sound Seeking Strategy

- Two interconnecting neurons provide the basis for the strategy.
- Logic of movements to move to sound source:



Sound Sensor Evaluation

- **Directivity**: Omni-Directional

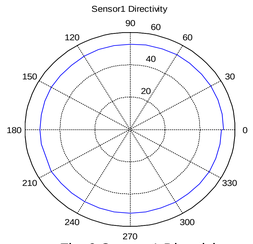


Fig. 3 Sensor 1 Directivity

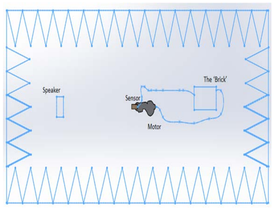


Fig.4 Directivity Test Setup

- **Sampling Frequency**: ≈ 300 Hz

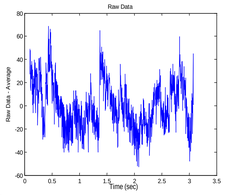


Fig. 5 Sensor 1 Raw, Source 50Hz

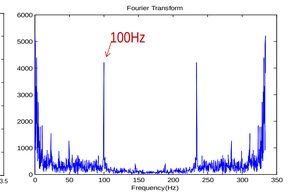


Fig. 6 Sensor 1 FFT, Source 50Hz

Signal Frequency	50Hz	75Hz	100Hz	125Hz	150Hz
Measured by Sensor 1	100Hz	150Hz	150Hz	100Hz	50Hz
Measured by Sensor 2	100Hz	150Hz	150Hz	100Hz	50Hz

Table 1: Summary of Signal Frequencies and Frequencies Measured by Sensor 1 & 2

Sound Sensor Calibration

- Why:
  - ✓ Remove measurement differences between the two sensors.
- **Cable/Port Stability**:

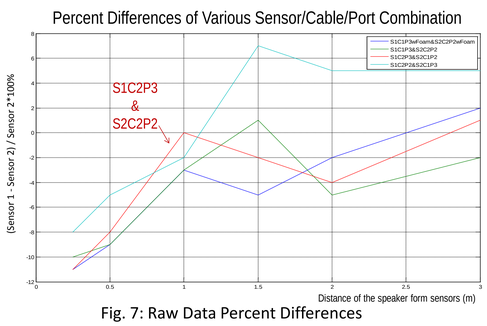


Fig. 7: Raw Data Percent Differences

For the setup S1C2P3 & S2C2P2, S1 reads constantly smaller than S2 within 2.5m.

Raw Data Range	<170	[170, 250]	[250, 450]	[450, 650]
Percent Difference (S1-S2)/S2 *100%	-2.5%	-0.3%	-8%	-11%

Table 2: Percent Difference with Respect to Raw Data Range, S1C2P3/ S2C2P2

Sound Seeking Result

Speaker Location: 2.30m, 50° left from normal to Lego's Starting Point

- **Movement 1: No Obstacle**

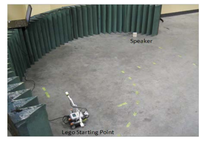


Fig.8: Movement 1 Lab Setup

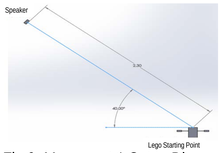


Fig.9: Movement 1 Setup Diagram

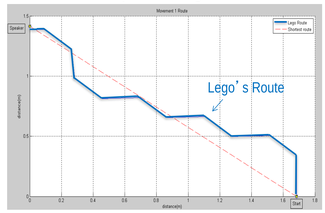


Fig.10: Lego Movement 1 Diagram

- **Movement 2: One Obstacle**

Fig.11: Movement 2 Lab Setup

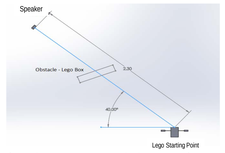


Fig.12: Movement 2 Setup Diagram

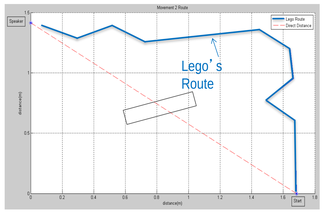
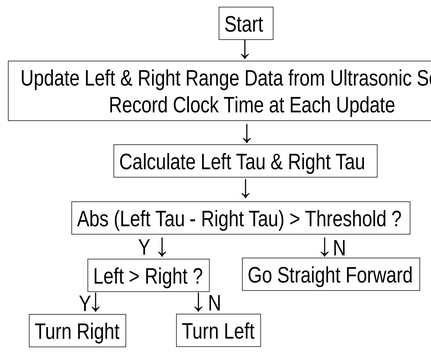


Fig.13: Lego Movement 2 Diagram

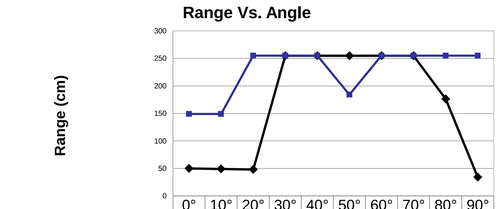
Collision Avoidance

- Flow field. Echoic Flow: Tau = $r.\Delta t / \Delta r$, a direct measure of the current time to collision.
- Logic of movements based on a 2-neuron system:



Preliminary Navigation Result

- Ultrasonic Sensor :



	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
average distance(50)	50	49.08	48	255	255	255	255	255	176.2	34
average distance(150)	149	149	255	255	255	184	255	255	255	255

Fig. 14: Range Readings at Fixed Range, Various Angles

Fig. 15: Lego passes through a corridor

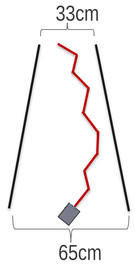


Fig. 16: Lego route inside corridor

Conclusions

- Two – neuron systems can exhibit complicated behavior such that:

1. The sound source seeking robot:

   Successfully moved to the sound source (in working range).

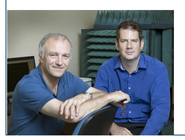
   It only compares received sound signal in each sensor regardless of starting position.

2. The robot can navigate around obstacles without colliding using echoic flow.

- The simple Lego sensors and motors limit the robots' performance, but are still able to demonstrate complex behavior.

References

- Webb, Barbara. Using robots to model animals: a cricket test. *Robotics and Autonomous Systems,* 16:117-134 (1995).
- Prochnow, Dave. *LEGO Mindstorms NXT Hacker's Guide*. McGraw-Hill Companies, Inc., 2006.



- Smith, Graeme E., and Baker, Christopher J., "Echoic flow for radar and sonar". *ELECTRONICS LETTERS*. Vol.48, No.18, p. 1160 – 1161.
- RWTH - Mindstorms NXT Toolbox. *http://www.mindstorms.rwth-aachen.de/trac*.