MERIT FAIR
BIEN 2009

Bat-Inspired Robot Navigation

Michael J. Kuhlman and Katherine M. McRoberts
Advisors: Timothy K. Horiuchi and P.S. Krishnaprasad

Intelligent Servosystems Laboratory

A Navigation Problem

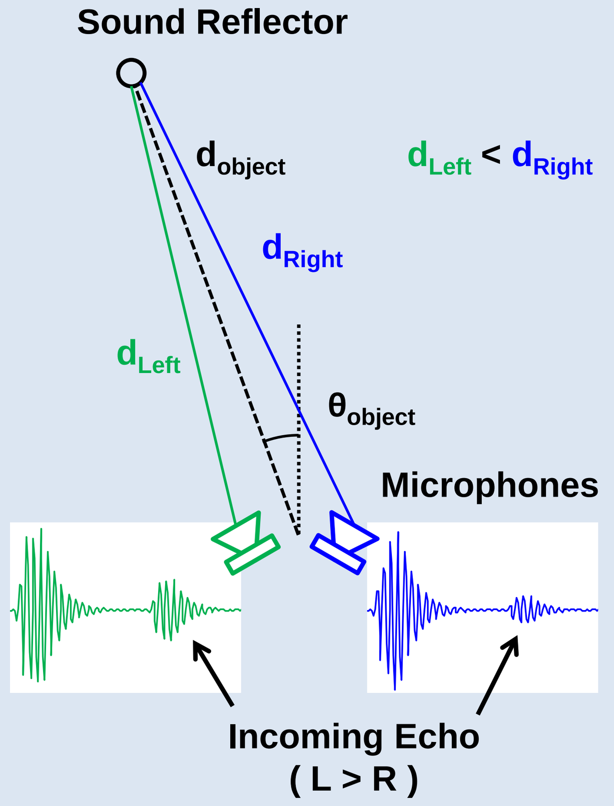
Bats' seemingly effortless navigation abilities have long fascinated scientists. We designed and implemented a system that enabled a robot to exhibit obstacle avoidance using echolocation.

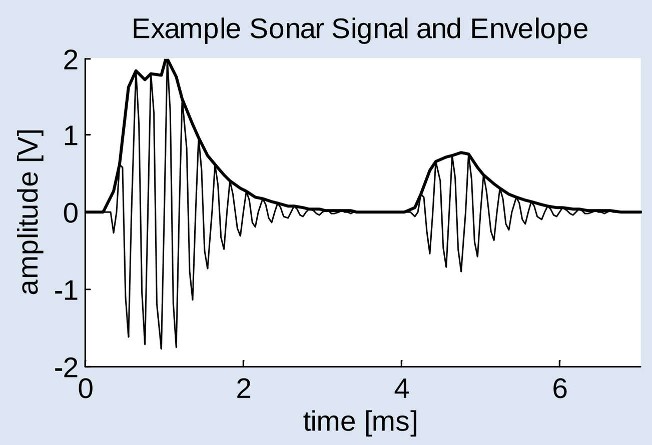
Image available at: http://picasaweb.google.com/lh/photo/CUVA1rKZBoKvE3tbR6xn3g

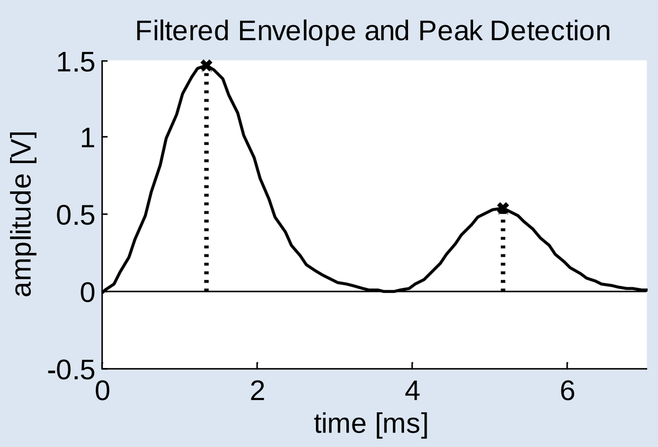
Sonar System and Obstacle Detection

Information about an obstacle's location lies in the differences between echoes in the left and right microphones.

- Figure depicts sonar system:
  - Speaker (like bat's mouth) emits 40 kHz ultrasonic pulses
  - Two microphones (like bat's ears) receive echoes off nearby objects
- Echo is weaker in right microphone:
  - Directionality of microphone
  - Acoustical shadowing
  - Difference in distance





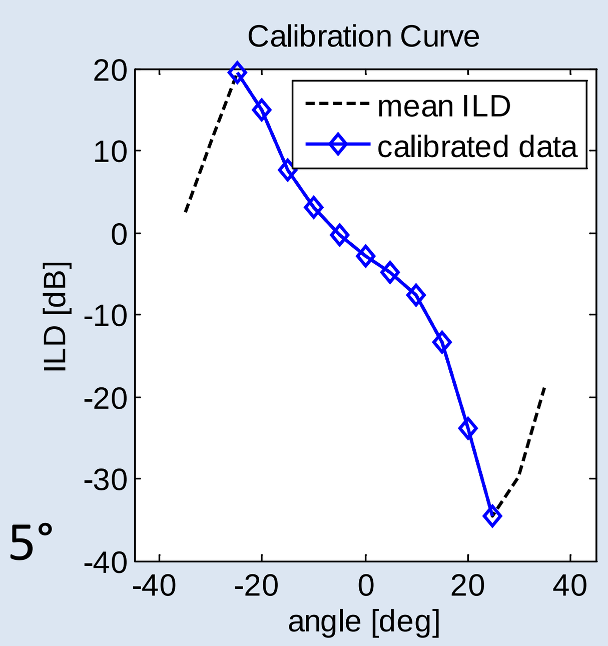


- MATLAB code filters signal envelope and detects peaks by locating derivative sign changes
- Outgoing pulse creates first peak; successive peaks are from echoes
- Amplitudes and times of echo peaks from each channel determine obstacle location (specified by distance and angle)

- Interaural Level Difference (ILD) compares echo magnitudes in left and right microphones to determine angle:

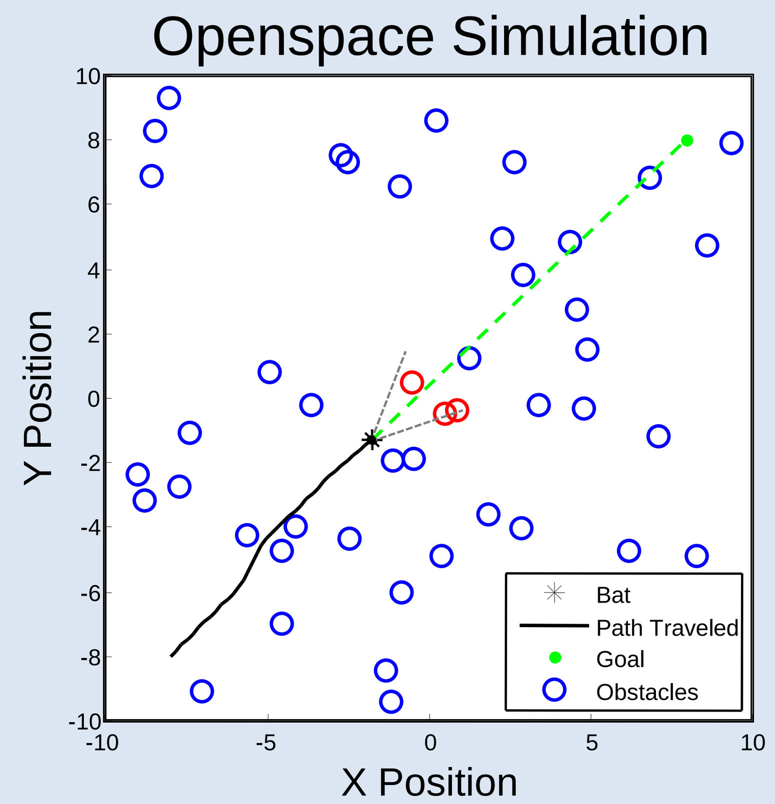
$$ILD = 20\log\left(\frac{\textit{Left Peak Amplitude}}{\textit{Right Peak Amplitude}}\right)$$

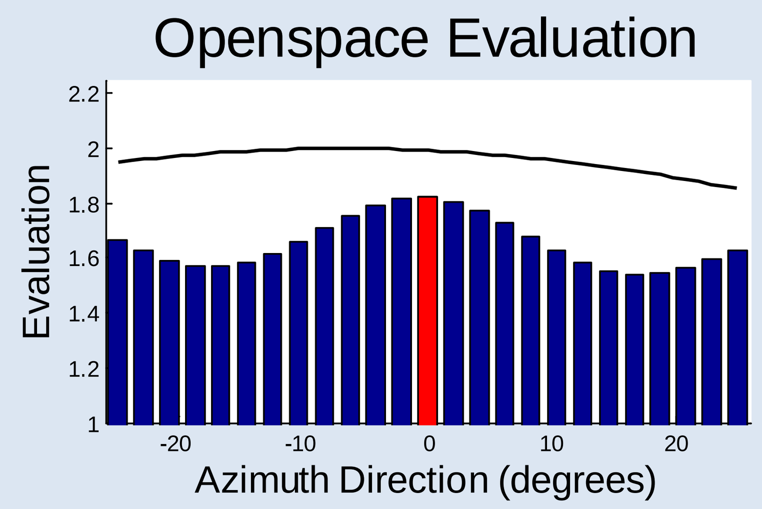
- 76% of trials estimated angle within ± 5°



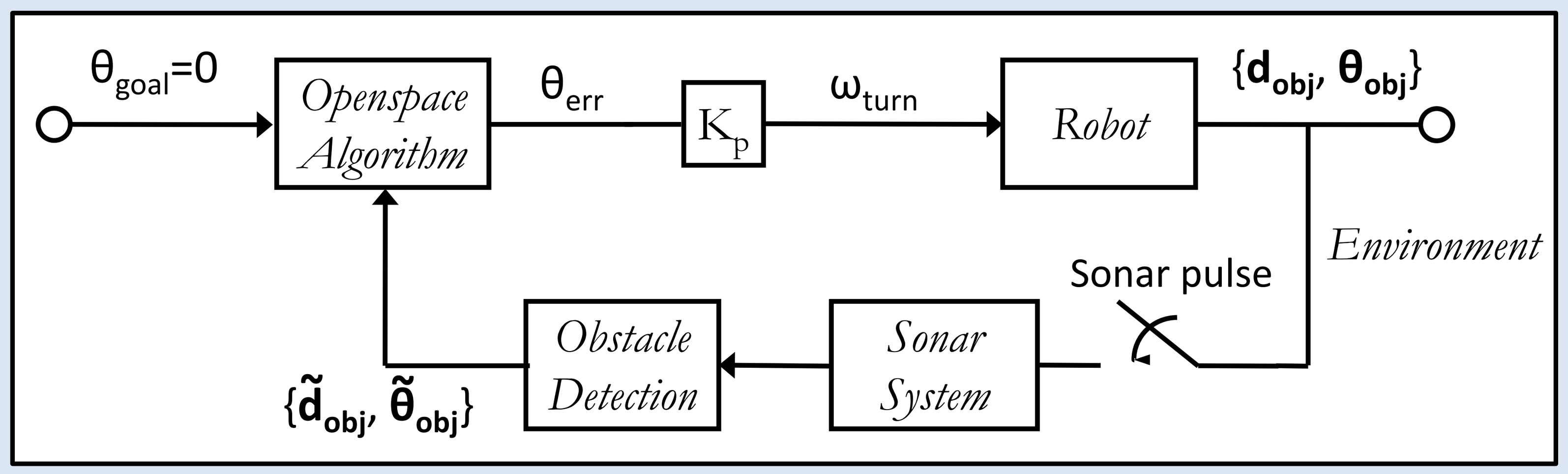
Openspace Motion Planner

- In the MATLAB *Openspace* simulation, bat evaluates environment to develop best path to goal
- Evaluation function calculates the desirability of traveling in each possible direction based on the locations of the goal and obstacles
- Additive Gaussian accounts for goal steering
- Suppressive Gaussians account for each impeding obstacle
- Winner-take-all selection chooses the direction with the maximum evaluation (red bar in figure)





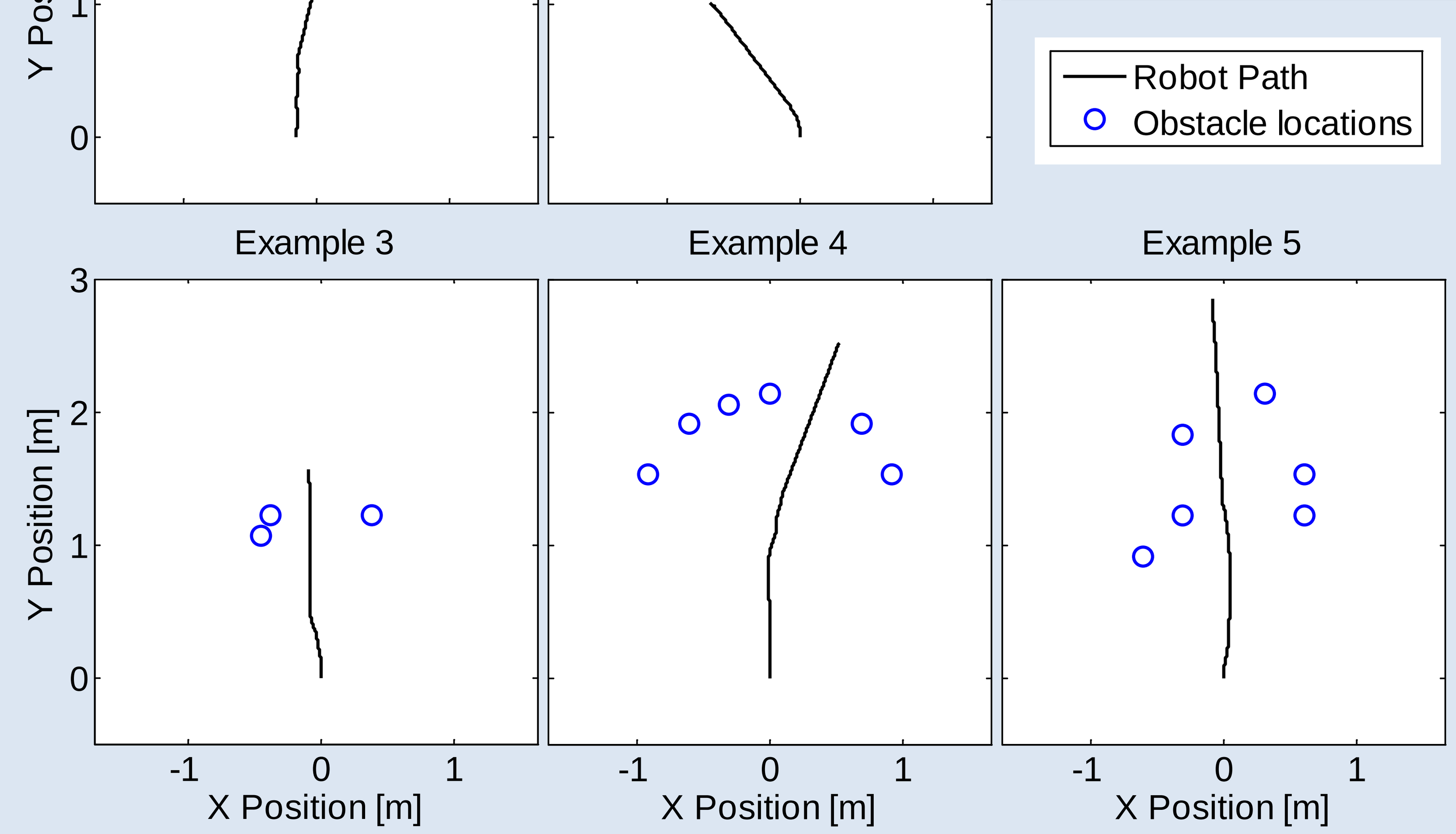
System Overview

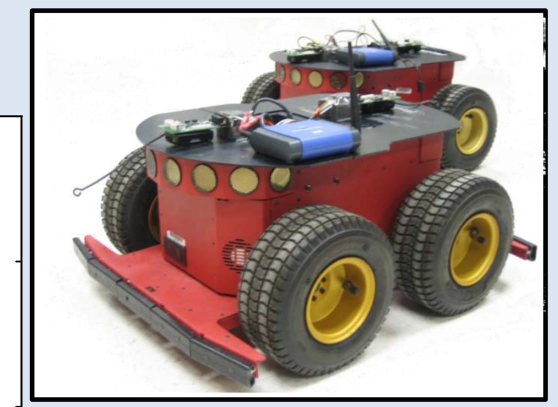


This figure details the flow of data in the real-time system. Once the *Openspace* evaluation function calculates the winner-take-all angle, a proportional controller adjusts the robot's movement accordingly. Then the sonar system and obstacle detection code re-evaluate the environment to provide feedback.

Robot Performance

The robot displayed successful wander behavior through a variety of obstacle fields.





- Ex. 1: Robot can safely fit through obstacles
- Ex. 2: Robot correctly determines that the gap is too narrow and moves towards the outside
- Ex. 3: Abutting obstacles are treated as one and do not steer the robot too far to the right
- Ex. 4: Robot finds the largest gap through which to travel
- Ex. 5: Robot maneuvers through random obstacle field

Conclusions and Future Work

Overall, the *Openspace* algorithm and sonar system worked together harmoniously, successfully navigating the robot through significant obstacle arrangements. Future developments would include incorporation of a GPS system to allow for world-coordinate feedback.

Acknowledgements

The authors would like to thank Graham Alldredge, Chetan Bansal, and Matteo Mischiati for their technical advice and assistance, as well as the Intelligent Servosystems Laboratory, the Computational Sensorimotor Systems Laboratory, the MERIT program, and the NSF.

References

[1] Shi, R.Z. and Horiuchi, T.K. 2007. IEEE Transactions on Circuits and Systems I: Regular Papers **54** 74-88.
[2] Horiuchi, T.K. *A Spike-Latency Model for Sonar-Based Navigation in Obstacle Fields*, Institute for Systems Research (preprint), 2008.
[3] D. Hirstu-Varsakelis et. al. *A Motion Description Language for Hybrid System Programming*, Institute for Systems Research (preprint), 2008.