Robotic Sensing
Guiding Undergraduate Research Projects

Arye Nehorai
Center for Sensor Signal and Information Processing (CSSIP)
Signal Processing Innovations in Research and Information Technologies (SPIRIT) Lab

January 2010
ESE Launching Multi-team Robotic Sensing Project

- We created a new multi-team undergraduate project entitled Robotic Sensing
- Students will take leadership roles in multi-semester projects
- Students will implement sensor systems for mobile robots that make autonomous decisions based on the sensed environment
- These systems include acoustic, chemical, RF electromagnetic, infra-red, and visual sensors
- The project is multidisciplinary, involving hardware, signal processing, imaging, control, communications, and computer interfaces
- It is led by the department chair, Dr. Arye Nehorai
Robotic Sensing – Multi-Team Project

Hardware Design

- Physical/Chemical/Biological Background
- Transducer/Sensor Selection
- Signal Conditioning (analog filter, signal amplifier)
- Data Acquisition System (sampling rate and resolution)
- Microcontroller
- Actuators (motors)

Software/Interface Design

- Graphical User Interface (GUI) Design
- Graphical display of variables of interest
- User-defined System and Algorithms parameters
- Real-time Data Processing Architectures

Algorithm Design

- Preprocessing Algorithms (Digital filters: FIR, IIR)
- Statistical Signal Processing Algorithms

Robotic Platform

Central Processing

Communication
Robotic Sensing – Multi-Team Project

- Microphones
- Chemical Sensors
- Ultrasound Sensors
- Infrared Sensors
- Acoustic Vector Sensors
- Camera Sensors
- Microcontroller
- Servo Motor
- Data Acquisition
Robotic Sensing: Current Projects

Advisor: Dr. Arye Nehorai

- **Chemical Sensors**
  - Chemical source position estimation (Joy Chiang)

- **Acoustic Vector Sensors**
  - Acoustic vector sensors for source location (Evan Nixon)

- **Microphones**
  - Adaptive source position estimation (Raphael Schwartz and Zachary Knudsen)

- **Ultrasound Sensors**
  - Real-time tracking (Andrew Weins)

- **Servo Motor**

- **Microcontroller**

- **Chemical Sensors**

- **Data Acquisition**
Robotic Sensing: Adaptive Microphone Arrays

**Goal:** To modify microphone array configuration adaptively for improving the performance in estimating acoustic source position using generalized cross-correlation algorithms.

Current projects supervised by Professor Arye Nehorai

- **Chase LaFont**, *Algorithms for sensing parameter adaptation*, since summer 2009
- **Raphael Schwartz** and **Zachary Knudsen**, *Data architectures for real-time acoustic source position estimation*, since summer 2009
Hardware Design

Physical/Chemical/Biological Background

\[ \theta = \cos \left( \frac{v_x (\text{TimeDelay})}{d} \right) \]

\[ x^* = \frac{P}{2} \frac{[\tan(\theta_2) + \tan(\theta_1)]}{\tan(\theta_2) - \tan(\theta_1)} \]

\[ y^* = -P \frac{\tan(\theta_2) \tan(\theta_1)}{\tan(\theta_2) - \tan(\theta_1)} \]
Algorithm Design

Physical/Chemical/Biological Background

Statistical Signal Processing Algorithms

Measurement Model

\[ x_1(t) = s_1(t) + n_1(t) \]
\[ x_2(t) = \alpha s_1(t + D) + n_2(t) \]

Time-delay estimation

DOA estimation at each microphone

\[ \theta_i = \cos^{-1} \frac{v s_i \hat{D}_i}{d} \]
Algorithm Design (Cont.)

Statistical Signal Processing Algorithms

Region of Ambiguity

Higher Resolution

Microphones pairs

$X_s = 1.949 \quad Y_s = 2.045 \quad \text{Error} = 0.0680$

$X_s = 2.323 \quad Y_s = 2.405 \quad \text{Error} = 0.5180$

$X_s = 1.949 \quad Y_s = 1.944 \quad \text{Error} = 0.0757$

$X_s = 1.949 \quad Y_s = 2.045 \quad \text{Error} = 0.0680$
Hardware Design

Transducer/Sensor Selection

Koss M-18 electret microphones

Signal Conditioning

DC Blocking Filter Diagram

Data Acquisition System

DAQ

Microcontroller

NXT ARM7

Actuators

Servomotor

Robotic Microphone array
Software/Interface Design

Graphical User Interface (GUI) Design

GUI using Matlab

User-defined System and Algorithms parameters

Real-time Data Processing Arquitectures

Graphical display of variables of interest

- Sensor array configuration
- Data acquisition system
- Preprocessing filters
- Cross-correlation algorithm

Real time source location

Spectrogram

Estimated location
Robotic Microphone Array

Measurements

Statistical Signal Processing & Position Control Algorithms

New array Configuration

Resolution

Error
Robotic Microphone Array

Robotic Platform 1
- NTX
- Pair of Motors
- Sensing Acoustic Field
  - Pair of Microphones + DAQ

Computer for Central Processing
- Source Position Estimation
- Sensing parameter adaptation

Feedback

Robotic Platform 2
- NTX
- Pair of Motors
- Sensing Acoustic Field
  - Pair of Microphones + DAQ
Microphone Array Demonstration

Demonstration at the WUSTL Undergraduate Research Symposium,
October 24th, 2009
Microphone Array Demonstration (Cont.)

Demonstration at the WUSTL Undergraduate Research Symposium, October 24th, 2009
Robotic Sensing: Acoustic Vector Sensors

**Goal:** Estimate the position of an acoustic source using spatial and temporal measurements of pressure and particle acoustic field

**Acoustic vector sensor (AVS)**

**Measurement model**

\[ \mathbf{v}(r, t) = -\frac{p(r, t)}{\rho_0 c} \mathbf{u} \]

- \( p(r, t) \) pressure at position \( r \) and time \( t \)
- \( \mathbf{v}(r, t) \) particle velocity at position \( r \) and time \( t \)
- \( \mathbf{u} = [\cos \phi \cos \psi, \sin \phi \cos \psi, \sin \psi]^T \) direction of particle velocity
- \( c \) speed of sound, \( \rho_0 \) Ambient pressure

**Current projects supervised by Professor Arye Nehorai**

- Ian Beil and Evan Nixon, *Acoustic vector sensors for source location*, since Fall 2009
Robotic Sensing: Acoustic Vector Sensors (Cont.)

Above: Diagram of experimental setup; Power distribution as a function of azimuth and elevation. The red arrow indicates the maximum spectral value.

Right: Experimental setup at SPIRIT LAB
Robotic Sensing: Current Projects
Advisor: Dr. Arye Nehorai

Microphones

Chemical Sensors

Ultrasound Sensors

Infrared Sensors

Acoustic Vector Sensors

Data Acquisition

Servo Motor

Microcontroller

Camera Sensors